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Proceedings of the American Academy of Arts and Sciences.

Vol. XXXII. No. 1. — November, 1896.

CONTRIBUTIONS FROM THE GRAY HERBARIUM OF HARVARD UNIVERSITY.

New Series. — No. X.

By B. L. Robinson and J. M. Greenman.

I. Revision of the Genus *Tridax*.

II. Synopsis of the Mexican and Central American Species of the Genus *Mikania*.

III. Revision of the Genus *Zinnia*.

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CONTRIBUTIONS FROM THE GRAY HERBARIUM OF HARVARD UNIVERSITY, NEW SERIES, No. X.

By B. L. Robinson and J. M. Greenman.

Presented May 13, 1896.

I. — REVISION OF THE GENUS TRIDAX.

TRIDAX, L. (Name supposed to come from τρίς, thrice, and δακεῖν, to bite, referring to the trifid rays.) — Heads terminal upon long peduncles, heterogamous and radiate or rarely homogamous and discoid. Involucre campanulate to sub-cylindric, 2 – several-seriate, very rarely sub-uniseriate; scales all or at least the inner scarious and commonly purple-margined. Receptacle mostly conical. Ray-flowers, when present, fertile; ligules yellow, white, or roseate, clearly or obsoletely bilabiate; external lip 3-toothed or deeply trifid, obovate or oblong in outline, patulous; the inner of 1 or 2 short erect teeth or sometimes wanting; disk-flowers usually (if not always?) yellow, regular, 5-toothed. Anthers short, sagittate at the base, appendaged at the apex. Style-branches terminating in short or long subulate appendages. Achenes turbinate, hirsute or upwardly silky-villous, very rarely glabrous or nearly so. Pappus of several to many narrow ciliate scales attenuate to plumose awns (except in *C. dubia*). — Hort. Cliff. 418, & Gen. no. 979; DC. Prodr. v. 679; Benth. & Hook. f. Gen. ii. 392; Hoffm. in Engl. & Prantl, Nat. Pflanzenf. iv. Ab. 5, 247. *Bartolina*, Adans. Fam. ii. 124. *Sogalgina*, Cass. Bull. Philom. 1818. & Dict. Sci. Nat. xlix. 397. *Bulbisia*, Willd. Spec. iii. 2214. *Galinsogea*, HBK. Nov. Gen. & Spec. iv. 252, t. 386. *Ptilostephium*, HBK. l. c. 253, t. 387, 388. *Carphostelphium*, Cass. Dict. Sci. Nat. xliv. 62. *Mandonia*, Wedd. Bull. Soc. Bot. Fr. xi. 50, t. 1, not Schz. Bip. — Pubescent annuals or perennials not rarely lignescent at the base, with leaves opposite, petiolate or subsessile, subentire or more often dentate or irregularly cleft or pinnatifid. About 22 known species, two of them of the S. American Andes, the others confined to Mexico, except a single species which extends also to Mauritius and E. India.

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Subgenus EUTRIDAX. Scales of the involucre 2 – several-seriate: achenes densely silky-villous or hirsute: pappus scales terminating in plumose awns.

§ 1. Scales of the involucre very unequal, regularly imbricated in several to many series, gradually decreasing in size; the outermost very short, mostly scarious and rounded at the summit, very rarely somewhat herbaceous or (in *T. angustifolia*) subacute.

* Heads discoid: pappus shorter than the achenes.

1. T. brachylepis, Hemsl. "Annual, erect," with "slender glabrescent branchlets" and "thickish ovate-lanceolate dentate or sometimes obscurely lobed leaves." — Biol. Cent.-Am. Bot. ii. 207. — Cordillera of Oaxaca, altitude 7,000 feet, *Galeotti*. The only specimen, seen by the writers, closely approximating in its characters Mr. Hemsley's description is no. 1423 of *E. W. Nelson*, collected in the Valley of Oaxaca, altitude 5,500 to 7,500 feet, 20 September, 1894. But although only the upper portion of the root is at hand it is not unlikely perennial.

2. T. tuberosa. Distinctly perennial; the elongated woody root at places tuberous-thickened: stem decumbent, subsimple, 3 feet in height, leafy to the middle, hirsute: leaves hirsute upon both surfaces, 3-nerved, 2 inches long, nearly half as broad, cuneate at the base and 3-cleft with sharply toothed acute lobes: heads about 6, nearly 7 lines long and 6 lines in diameter: pappus only a third to half the length of the achene. — Collected by *C. G. Pringle*, on the Sierra de San Felipe, Oaxaca, altitude 7,000 to 8,500 feet, 17 November, 1894, no. 5644 a.

3. T. Pringlei. Perennial, decumbent, much branched from near the base, 2 feet high, pubescent throughout but less hirsute than the preceding: root woody, tuberous-thickened at intervals: leaves lanceolate, dentate or subentire, obtusish, 1 to 1½ inches long, scarcely a third as broad, 1-nerved: heads 2 to 4, very similar in all respects to those of the preceding. — Collected by *C. G. Pringle*, on the Sierra de San Felipe, Oaxaca, altitude 7,500 feet, 7 September, 1894, no. 5644. In technical characters very close to the preceding species, but with markedly different foliage.

* * Heads radiate: ligules evident.

+ Mexican species.

++ Rays yellow.

= Pappus very short or none.

4. T. trilobata, Hemsl. l. c. 208. Erect much branched glandular-pubescent annual, a foot or two high, with lance-oblong obtusish and coarsely few-toothed or laciniate leaves (cuneate at the base) and numer-

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ous showy heads 10 lines to an inch in diameter, with dark purple involucre and broad bright orange-yellow rays. — *Galinsoga trilobata*, Cav. Icon. iii. 42, t. 282; Bot. Mag. t. 1895; Sweet, Brit. Fl. Gard. t. 56. *Sogalgina trilobata*, Cass. Dict. Sci. Nat. xlix. 397. — Valley of Mexico, *Bourgeau*, no. 846; near Chapultepec, *Schaffner;* and on calcareous bluffs, Flor de Maria, *Pringle*, no. 3148; also in Michoacan in fields near Patzcuaro, *Pringle*, no. 4271. The form without any trace of pappus does not appear to differ in any other particular. A specimen cultivated in the Botanic Garden of Harvard University has leaves oblong, subentire.

= = Pappus about equalling or somewhat exceeding the achenes.

5. T. balbisioides, Gray. Annual, much branched, pubescent: branches divaricate or the lowest decumbent: leaves from lanceolate and irregularly toothed to deeply ternately cleft or pinnately parted: heads rather numerous, nearly or quite an inch in diameter, with convex or conical disk and spreading showy rays: ligules (exclusive of tube) 2½ to 4 lines long, as broad or broader. — Proc. Am. Acad. xv. 39. *T. coronopifolia*, Gray, l. c., not Hemsl. *Galinsogea balbisioides*, HBK. Nov. Gen. & Spec. iv. 253, t. 386. *Sogalgina balbisioides*, Cass. l. c. xlix. 398. — Originally collected in Guanajuato between the Valley of Santiago and Lake Palangeo, at 5,500 feet altitude, by *Humboldt & Bonpland.* It is described and figured by Kunth, l. c., as having entire or repand ligules of suborbicular contour. No plants with this character have since been observed, and we follow Dr. Gray in referring to the species the following, which differ only in their more or less distinctly 3-toothed rays: *Schaffner's* no. 238, and *Parry & Palmer's* no. 509, both from San Luis Potosi. Nor does *T. leptophylla*, Gray (l. c. xxi. 391), from Chihuahua (*Palmer's* no. 425, and *Pringle's* no. 769), appear to differ by any constant or satisfactory character. A form from San Luis Potosi, represented by *Parry & Palmer's* no. 508, has the ligules sometimes 3-toothed and sometimes divided nearly to the base into 3 oblong lobes. This plant was rather confidently referred by Dr. Gray (l. c. xv. 39) to *T. coronopifolia*, but it differs from that species decidedly in its much imbricated involucre, with very unequal and rounded scales, and in its attenuate chaff. Nor is the ligule strap-like. In stating it to be so Dr. Gray had presumably observed only one of the long oblong lobes of a very deeply trifid ray.

6. T. petrophila. Distinctly perennial from a lignescent base: stems several, very slender, erect or nearly so: branches ascending: leaves very narrow, linear, entire, toothed, or with 2 or 3 short linear lobes:

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ray-flowers with ligules much smaller than in the preceding, about 1½ lines in diameter: the tube being relatively very long and slender (4 to 5 lines in length): chaff terminating in a long and slender awn. — *T. balbisioides*, Gray, l. c. xxii. 430, not xv. 39. *T. balbisioides*, var. *tenuifolia*, Gray, (ined.) in distribs. Palmer and Pringle. — Jalisco, on the Rio Blanco, *Palmer*, no. 569; on rocky hills near Guadalajara, *Pringle*, nos. 2179, 2556. The later collections of Mr. Pringle show this plant quite distinct in its woody base and reduced rays from *T. balbisioides*.

+ + Rays white, purplish, or roseate.

= Pappus much longer than the achene.

7. T. rosea, Schz. Bip. in herb. Hirsutulous annual, leafy near the base and often with spreading branches: leaves linear-oblong, irregularly toothed or trifid with toothed lobes: peduncles becoming very long (6 to 10 inches), quite simple, naked or bearing 1 or 2 minute alternate bracts: heads large, with the spreading rays an inch or more in diameter: ligules oblong, 3 to 5 lines in length, slightly 3-toothed at the apex. — A good but apparently unedited species, founded by Schultz upon *Schaffner's* no. 60, from Guadalupe, and collected in the same locality by *Bilimek* in 1865, no. 488, and *Bourgeau*, no. 586; also in Valley of Mexico, *Schaffner*, no. 265.

= = Pappus shorter than or barely equalling the achene.

8. T. Palmeri, Gray. Pubescent or puberulent, 2 feet high, usually with a few ascending branches, naked above: leaves mostly much cleft or deeply and laciniately parted into narrow acute segments: rays broad, obovate, truncate, essentially entire, roseate: disk-flowers greenish yellow. — Proc. Am. Acad. xv. 38. — San Luis Potosi, on rocky bluffs at Alvarez, altitude 8,000 feet, *Parry & Palmer*, nos. 489, 490, 482½, also *Schaffner*, no. 236.

Var. indivisa. Robinson & Seaton. Somewhat stouter and more densely pubescent: leaves ovate, subhastate, abruptly contracted into a petiole, repand-dentate, not lobed. — Proc. Am. Acad. xxviii. 109. — Ledges of cañons on mountains near Lake Chapala, Jalisco, *Pringle*, no. 4332. Mr. Pringle states that the base is perennial.

+ + South American species, of the Andes of Bolivia and Ecuador: leaves narrow: pappus longer than the achenes.

9. T. Mandonii, Schz. Bip. Branched, hirsute: leaves sinuate or repand-dentate: involucral scales rounded at the apex, sparingly puberulent near the ends or quite glabrous: rays very small. — Bull. Soc. Bot. Fr. xii. 82, & Linnæa, xxxiv. 536. *Mandonia Boliviensis*. Wedd. Bull.

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Soc. Bot. Fr. xi. 51, t. 1. — Near Sorata, Province of Larecaja, altitude 2,690 to 3,000 meters, *Mandon*, no. 289.

10. T. angustifolia, Benth. & Hook. f. Decumbent and rooting at the nodes, pubescent: leaves lance-linear, acute, denticulate or entire: involucral scales acutish, pubescent or puberulent on the outer surface; the outer ones inclining to be squarrose: ligules oblong, 2 or 3 lines in length. — Gen. ii. 392. — Collected in the Andes of Ecuador by *Spruce*, no. 5582.

§ 2. Involucral scales 2-3-seriate, less unequal; the outer often herbaceous and acutish.

* Leaves ovate to linear, pubescent to densely hirsute but not canescent.

+ Leaves relatively broad, subentire, toothed, or divided into a few rather broad lobes.

++ Pappus longer than or about equalling the achenes.

= Perennials with ligneous or lignescent base: rays short, nearly orbicular, 3-toothed.

11. T. procumbens, L. More or less densely hirsute with white hairs: stems several to many from a woody root or stock, decumbent or procumbent: leaves lanceolate to ovate-lanceolate, acute, sharply repand- or sinuate-toothed, cuneate at the base: scales of the involucre oblong, acutish, usually villous-hirsute: chaff persistent: rays yellow or (?) white. — Spec. ii. 900. *Amellus pedunculatus*, Ort. *fide* Willd. Enum. 916. *Balbisia elongata*, Willd. Spec. iii. 2214. *B. pedunculata*, Hoffmgg. Verz. Pfl. 228. *B. divaricata*, Cass. Ann. Sci. Nat. xxiii. (1831) 90. — The most widely distributed species; Monterey, North Mexico, *Eaton & Edwards*, also *Pringle*, no. 1920; Wartenberg, near Tantoyuca, *Ervendberg*, no. 61; San Luis Potosi, *Parry & Palmer*, no. 520; "Coahuila and Nuevo Leon," *Palmer*, nos. 629, 2061; Orizaba, *Schaffner*, *Gray*, *Botteri*; Jalisco, *Palmer*, no. 297; Colima, *Palmer*, no. 1186; Oaxaca, *L. C. Smith*, no. 423, *E. W. Nelson*, nos. 2582, 2773; Guatemala, nos. 2370, & 4200 of Donnell Smith's sets. Also on Elliott's Key, Fla., *Simpson*, no. 553; Cuba, *Wright*, no. 2861. Introduced and now abundant in E. India and Mauritius.

Var. ovatifolia. Less hirsute, pubescence shorter, finer, and tending to become fuscous: base of stem ligneous: leaves ovate, acutish, serrate with small subequal obtusish teeth, finely pubescent upon both surfaces, 8 to 10 lines long, 6 to 8 lines broad, rather abruptly contracted at the base into short petioles: involucral bracts very broad, mostly obovate. — Collected by *E. W. Nelson* in the vicinity of Yalalag, Oaxaca, July, 1894, no. 948. Rather well marked in its foliage and possibly a distinct

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species, but agreeing with the type in all floral characters except the somewhat broader involucral scales.

= = Annuals.

12. T. obovata, Turcz. Low, 4 to 6 inches in height: leaves obovate, subentire, obtuse: ligules short, yellowish. — Bull. Soc. Nat. Mosc. xxiv. 187; Walp. Ann. 238. — S. Mexico, on Sierra San Pedro, Nolasco, Talea, &c., *Jurgensen*, no. 124. Here we would refer specimens collected near Acapulco by *Palmer*, no. 165.

13. T. erecta, Gray. Slender, erect, hirsutulous, branching, a foot or so in height: leaves ovate-lanceolate and serrate or broadly ovate in outline and rather deeply 3-parted with acutish lobes: heads rather small: involucre ovate; one or two of the outer scales often narrow, oblong, and spreading: ligules short, only a line or two in length, 3-toothed, yellow. — Proc. Am. Acad. xxi. 390, 433. — Southwestern Chihuahua, *Palmer*, no. 285.

14. T. tenuifolia, Rose. Erect, pubescent, 1 to 2 feet high, branching: leaves ovate, petiolate, dentate but not lobed: outer scales of the involucre acuminate: rays conspicuous, 3 to 5 lines long, pale yellow or "bright white." — Contrib. U. S. Nat. Herb. iii. 319. *T. bicolor*, Gray, Proc. Am. Acad. xxi. 391, as to pl. Palmer. — Southwestern Chihuahua, on mountain sides above Batopilas, *Palmer*, no. 130.

Var. microcephala, Rose, l. c. Described as differing in its smaller heads and "slightly different disk corollas." — "Near Lodiego, *Palmer*, no. 1611."

+ + Pappus shorter than the achenes.

= Annual species of Northwestern Mexico: heads large, an inch in diameter.

15. T. bicolor, Gray. Erect annual, with leaves ovate to rather narrowly oblong-lanceolate, serrate-dentate, not lobed, narrowed to slender petioles: ligules reddish or purplish, cuneate-oblong, 3-toothed. — Pl. Fendl. 104. — Llanos in the Sierra Madre, W. Chihuahua, *Wislizenus*, no. 214; also among rocks, Bachimba, *Thurber*, no. 833, and on rocky hills near the town of Chihuahua, *Pringle*, no. 638.

= = Species of Southern Mexico, lignescent at the base.

16. T. Galeottii, Klatt. "Stem terete, branched, pilose: leaves petiolate, cuneate, irregularly lobed, pilose upon both surfaces, 2 inches long, 1½ inches broad, 3-nerved: heads solitary, terminal; involucral scales biseriate, the outer shorter: chaff 3–5-dentate at the apex." — Leopoldina, xxiii. 6. *Ptilostephium Galeottii*, Schz. Bip. *fide* Klatt, l. c. — Between San Andres and San Miguel, *Liebmann*, nos. 588, 693, and

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Galeotti, no. 2472. A species not seen by the writers. The description is translated and condensed from the original characterization.

+ + Leaves very narrow, linear or lance-linear, or deeply cleft into narrow divisions: heads rather small, 4 to 6 lines broad: rays small, bilabiate, the external lip trifid.

17. T. coronopifolia. Hemsl. Low, much branched and spreading, pubescent or hirsute; leaves lance-linear, denticulate, lacinately toothed or pinnatifid with narrow linear unequal acute segments: peduncles slender, toward the summit finely strigillose with appressed white hairs, and lacking the glandular-tipped hairs so common in the genus: rays yellow (or white): pappus scales unequal, some of them subulate and ciliated, others plumose with scarcely dilated base. — Biol. Cent.-Am. Bot. ii. 207. *Ptilostephium coronopifolium*, HBK. Nov. Gen. & Spec. iv. 255, t. 387. We have little hesitation in including in this species also *Tridax trifida*, Gray, Proc. Am. Acad. xv. 39 (*Ptilostephium trifidum*, HBK. l. c. 255, t. 388), notwithstanding the considerable difference in the pappus represented by Kunth. After the examination of a number of specimens we doubt the specific significance of the difference in length of the pappus, and as to the difference in the breadth of the scales that is often considerable upon the same achene. — Mexico without locality, *Th. Coulter*, nos. 348, 430, and *Berlandier;* State of Mexico, *Bilimek*, no. 491, also *Bourgeau*, nos. 164, 705; Tacubaya, *Schaffner;* Mt. Orizaba, altitude 9,000 feet, *Seaton*, no. 273; Oaxaca, Soledad de Etla, altitude 5,300 feet, *L. C. Smith*, no. 361, and by same collector at Telixtlahuaca, no. 866; also by *E. W. Nelson*, in Valley of Oaxaca, altitude 5,100 to 5,800 feet, no. 1229. The formal variety ALBORADIATA (*T. trifida*, var. *alboradiata*, Gray, Proc. Am. Acad. xv. 39), with white rays, but apparently without other significant or constant differences, has a somewhat more northerly distribution, having been collected at San Luis Potosi, *Schaffner*, no. 239, *Parry & Palmer*, no. 511; in Jalisco, *Pringle*, no. 2902; and in Guanajuato, *Dugès*, no. 438.

18. T. lanceolata, Klatt. "Lower leaves broadly lanceolate and upper lance-linear, entire: chaff obovate." — Leopoldina, xxiii. 6. — "Tehuacan, *Liebmann*, no. 205; Cuernavaca, *Berlandier*, no. 1063." A species not seen by the writers and (as to description) distinguished from the preceding species chiefly by the characters quoted.

19. T. imbricata, Schz. Bip. "Leaves linear-lanceolate, entire, or 1–3-toothed, pilose, ciliated on the margins: external scales of the involucre obtuse, striate, dorsally puberulent." — Schz. Bip. in Klatt, Flora, 1885, 202. — "Real del Monte, *Ehrenberg*, no. 355." We suspect this to be merely a form of *T. coronopifolia*.

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* * Whole plant canescent-tomentose: leaves linear, entire.

20. T. candidissima, Gray. Very white-woolly, 4 to 6 inches high, densely leafy below: leaves 1 to 1¾ inches long, sessile by a sheathing base: peduncles solitary, terminal, naked: heads homogamous: involucral scales lanceolate, acute: pappus long. — Proc. Am. Acad. xv. 39. — On ashy soil, Angostura, San Luis Potosi, *Parry & Palmer*, no. 510. Not since rediscovered.

Subgenus PSEUDOTRIDAX. Scales of the involucre sub-uniseriate: achenes merely papillose-puberulent or glabrescent: scales of the pappus obtuse or obtusish, laciniately bordered: anomalous species connecting this genus with *Galinsoga*.

21. T. (?) dubia, Rose. Decumbent or procumbent pubescent herb; stems about 2 feet long: leaves ovate, serrate, acutish, petiolate: heads subracemose or subcorymbose, 6 lines in diameter: involucral scales very few, about 5: ray-flowers with short golden yellow 3-toothed ligules. — Contrib. U. S. Nat. Herb. i. 337, t. 33. — Along river bottoms, Colima, *Palmer*, no. 1173; also in lowlands near San Blas, Tepic, *Lamb*, no. 609.

Species (doubtless of *Eutridax* but otherwise) of doubtful affinities: not seen by the writers.

22. T. Ehrenbergii, Schz. Bip. "Stem herbaceous, elongated, climbing, sulcate, sparingly pilose, trichotomous: leaves rhomboidal, slender-petioled, acuminately serrate, 3-nerved, above sparsely pubescent, below pilose upon the nerves: head solitary, terminal, many-flowered: involucre campanulate: scales scarious, laciniate on the margins: chaff scarious, trifid, costate, mucronate: flowers of the disk campanulate, pilose, ciliated on the margin: pappus-scales fimbriate, shorter than the sericeous achene." — Leopoldina xxiii. 6. — "Chinantla, *Liebmann*, no. 598. Leaves 20 lines long, 9 lines broad."

II. — SYNOPSIS OF THE MEXICAN AND CENTRAL AMERICAN SPECIES OF THE GENUS MIKANIA.

MIKANIA, Willd. (Dedicated to *Professor Joseph Gottfried Mikan*, of Prague, born 1743, died 1814.) — Cylindrical involucre of four erect concave obtuse or acute equal or subequal scales, sometimes with a shorter external fifth scale. Receptacle small, naked. Flowers 4 (in *M. punctata* "7"), tubular, with campanulate throat and 5-toothed limb. Anthers appendaged at the apex, obtuse or truncate at the base. Style-branches long, filiform-clavellate. Achenes 5-angled, without intermediate ribs,

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puberulent or glabrous. Pappus of many setæ in a single row, mostly about equalling or somewhat exceeding the achene, bright white or more commonly sordid, fuscous, or rufous. — Spec. iii. 1742; DC. Prodr. v. 187, vii. 270; Benth. & Hook. f. Gen. ii. 246; Hoffm. in Engl. & Prantl, Nat. Pflanzenf. iv. Ab. 5, 140. *Willugbæya*, Neck. Elem. i. 82. *Corymanthelium*, Kunze, Linnæa, xx. 19. — Mostly slender shrubby or herbaceous twiners or "rarely erect." Leaves opposite, usually ovate, cordate or hastate, and petiolate. Inflorescence spicately, racemosely, or corymbosely paniculate. A genus of some 175 good species nearly confined to Tropical or Subtropical America. *M. scandens* is also widely distributed in the United States and in the warmer parts of the Old World.

Subgenus 1. CYLINDROLEPIS. Truncate scales of the involucre not at all imbricated but strongly involute, each completely surrounding a flower.

1. M. globosa, Coulter. Glabrous or nearly so: leaves ovate, thickish, undulate-dentate, acuminate, rounded at the base, 5-nerved from near the base: heads in dense globose clusters; these in lateral or terminal panicles: each of the four flowers completely enveloped in an involucral scale: mature achenes not seen. — Bot. Gaz. xx. 46, where also called *Willugbæya globosa*. — Santa Rosa, Guatemala, altitude 4,000 feet, *Heyde & Lux* (no. 3430 of Donnell Smith's sets). A noteworthy species differing much in its involucral scales from any other known to us. It is said by Professor Coulter to resemble closely *M. smilacina* in "habit and structure." The likeness, however, does not extend to the heads, which are here completely divided into four compartments by the intrusion of the involute edges of the scales; while in *M. smilacina* the involucre is normally imbricated.

Subgenus 2. IMBRICATÆ. Scales of the involucre imbricated.

§ 1. Heads spicately or racemosely arranged on the opposite spreading branches of ample pyramidal panicles.

* Heads pedicelled.

2. M. Houstonis, Willd. Glabrous climbing shrub, with ovate acuminate entire petiolate leaves. — Spec. iii. 1742; DC. Prodr. v. 190. — S. Mexico, Vera Cruz, *Houston*, and (acc. to Hemsl.) "Linden, no. 1169; Yucatan and Tabasco. *Johnson*, no. 25; Guatemala, Las Escamillas, *Hartweg*, no. 535; Chojoja, near Mazatenango, *Bernoulli*, no. 100; Panama, Barbacoas, *S. Hayes*." The only plants in Herb. Gray agreeing with the character of this species are *Ervendberg's* nos. 87, 222, from Wartenberg, Huasteca, Mexico.

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* * Heads sessile.

+ Heads very small: pappus bright white: branchlets winged.

3. M. pterocaula, Schz. Bip. Glabrous twiner: leaves ovate, acuminate, dentate, thin, 5-nerved from the base: branchlets 6-winged. — Schz. Bip. in Hemsl. Biol. Cent.-Am. Bot. ii. 103 (name only); first described by Klatt, Leopoldina, xx. 4. — Mirador, *Liebmann*, no. 101.

+ + Heads larger: pappus tawny or rufescent: branchlets terete, striate but not winged: leaves entire.

4. M. leiostachya, Benth. Leaves large, firm in texture, ovate with acuminate apex and rounded base, pinnately 5-nerved from above the base, glabrous above, finely fuscous-pubescent on the veins beneath, at length wholly glabrate, the larger ones 3 or 4 inches in breadth: spikes 1 to 2 inches long. — Pl. Hartw. 201. — Columbia and Panama, *Seemann*, no. 446; also at Gatun Station, on the Panama Railway, *Hayes*. Said also to extend southward to Peru.

5. M. Hookeriana, DC. Leaves narrower, thinner, 3-nerved: spikes less than an inch in length: pappus rufous. — Prodr. v. 195. — Ascribed to Nicaragua and Panama by Hemsley. We have seen no specimens from any part of Mexico or Central America. The description is drawn from *Schomburgk's* no. 479 from Brit. Guiana.

§ 2. Heads not distinctly spicate nor racemose, disposed in ample terminal panicles: branchlets densely tawny-hirsute or woolly.

6. M. pyramidata, Donnell Smith. A tall climber densely covered with ferrugineous hirsute pubescence: panicle loose: heads not glomerate: leaves ovate, acuminate, rounded at the base, pinnately 5-nerved from somewhat above the base. — Bot. Gaz. xiii. 188. — Coban, Dept. Alta Verapaz, Guatemala, altitude 4,300 feet, *von Tuerckheim* (no. 1106 of Donnell Smith's sets).

7. M. eriophora, Schz. Bip. Densely tawny-tomentose, the inflorescence woolly: heads somewhat glomerate: leaves ovate, cordate, sharply acuminate, pubescent above, tomentose beneath, 5-nerved from the base, 3 to 4 inches long, 2 inches broad. — Schz. Bip. in Hemsl. l. c. (name only). — Mirador, *Liebmann*, no. 94.

§ 3. Heads disposed in roundish or flattish cymose corymbs.

* Heads rather large, when mature 4 to 5 lines in length.

+ Scales of the involucre obtuse: leaves ovate, distinctly cuneate at the base.

8. M. olivacea, Klatt. "Leaves entire." — Bull. Soc. Bot. Belg. xxxi. 195. — Forests of Buenos Ayres, Costa Rica, *Pittier*, no. 4433.

9. M. Guaco, Humb. & Bonpl. Leaves (*ex icone*) denticulate. — Pl. Æquin. ii. 84. t. 105. Said by Index Kew. to equal *M. amara*,

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Willd. Spec. iii. 1744, but apparently very different from Aublet's plate of *Eupatorium parviflorum*, Pl. Guian. ii. t. 315. — Nicaragua and Panama, acc. to Hemsley.

+ + Scales of the involucre obtuse: leaves cordate-hastate at the base.

10. M. punctata, Klatt, l. c. Heads described as 7-flowered. — Clairières du Général, Costa Rica, *Pittier*, no. 3434, and banks of a stream at Buenos Ayres by same collector, no. 4934.

+ + + Scales of the involucre acute: leaves cordate or hastate, rarely subtruncate at the base.

11. M. cordifolia, Willd. l. c. 1746. *M. suaveolens*, HBK. Nov. Gen. & Spec. iv. 135. *M. gonoclada*, DC. Prodr. v. 199. *M. Fendleri*, Klatt, Abh. Naturf. Gesellsch. Halle, xv. 4 (of reprint). — W. Louisiana, *Hale;* Mexico, San Luis Potosi, *Palmer*, nos. 1079, 1115, and on rocky slopes of Tamasopa Cañon, *Pringle*, no. 3928; Colima, *Palmer*, no. 1207; Acapulco, *Palmer*, no. 565; Cordova, *Bourgeau*, no. 1812; Wartenberg, Huasteca, *Ervendberg*, no. 82; Mirador, *Sartorius;* also somewhat doubtful specimens from Guatemala, altitude 4,600 feet, *Donnell Smith*, no. 2366, and Navarro, Costa Rica, by the same collector, no. 4855.

* * Heads decidedly smaller, 2½ to 3 lines in length.

12. M. scandens, Willd. l. c. 1743. Leaves smoothish, acuminate; hastate basal lobes little spreading. — *M. Orinocensis*, HBK. l. c. 134. *Eupatorium scandens*, L. Spec. ii. 836; Jacq. Ic. Rar. t. 169. — From N. Eng. to W. Canada, Florida, and Texas; Mexico, Victoria, Tamaulipas, *Berlandier*, nos. 852, 2272; San Blas, *W. G. Wright*, no. 1339; Cordova, *Bourgeau*, nos. 1632, 2184; Orizaba, *Botteri;* Oaxaca at Cuicatlan, *L. C. Smith*, no. 247, and near Reyes, *E. W. Nelson*, no. 1861; Guatemala, Esquintla, *Hayes*, Masagua, *Donnell Smith*, no. 2394, and Ambelice, *Heyde & Lux* (no. 3434 of Donnell Smith's sets); Nicaragua, *C. Wright;* Panama, *Seemann;* also W. India, Trop. Am., and warmer parts of the Old World.

13. M. denticulata, Willd. l. c. 1744. Leaves very scabrous, obtusish, hastate basal lobes widely spreading. — S. Mexico at Jalapa acc. to Lessing; Guiana, *Schomburgk.*

Dubious species.

M. ANGULATA, M. REPANDA, and M. TLALIXCOYAN, La Llave, El Mosaico Mexicano, ii. 299; Seemann in Hook. Jour. Bot. & Kew Misc. v. 79, from Cordova and vicinity, are unrecognized species founded solely upon foliar and very doubtful characters.

M. CORIACEA, La Llave, l. c., Seemann. l. c., is from its alternate leaves positively to be thrown out of the genus.

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III. — A REVISION OF THE GENUS ZINNIA.

ZINNIA, L. (Dedicated to *Professor Johann Gottfried Zinn*, of Göttingen, born 1727, died 1759). — Heads radiate: disk-flowers hermaphrodite, fertile; ray-flowers pistillate, fertile, with suborbicular oval or oblong sessile persistent white, yellow, red, or purple ligules. Involucre ovate-cylindric or campanulate, the scales 3 – many-seriate, broad, closely imbricated, obtuse or rounded, often more or less colored and slightly inflated or subsquarrose just beneath the summit. Disk conical to columnar: chaff scarious, more or less carinate, enveloping the flowers, often erose at the mostly obtusish apex. Corollas of the disk-flowers tubular with narrow scarcely ampliate throat and 5-toothed limb. Anthers appendaged at the apex, entire at the base. Style-branches obtuse, scarcely or not at all appendaged. Achenes laterally compressed, glabrous or ciliolate on the edges, 2-toothed at the summit and frequently 1-awned from the inner angle or rarely 2-awned; the achenes of the rays triquetrous, 3-toothed, with or without 1 to 3 short or long awns. — Gen. ed. 6, no. 974; Gray, Pl. Wright. i. 105; Benth. & Hook. f. Gen. ii. 357; Hoffm. in Engl. & Prantl, Nat. Pflanzenf. iv. Ab. 5, 225. *Crassina*, Scepin. Diss. and *Lejica*, Hill, Exot. Bot. t. 29, *fide* Endl. *Sanvitaliopsis*, Schz. Bip. acc. to Benth. & Hook. f., l. c. — Annuals, perennial herbs, or suffrutescent plants with opposite mostly entire leaves and showy terminal pedunculate or subsessile heads. About a dozen species known in nature, and three or four others somewhat doubtfully distinguished in horticulture, beside obviously artificial varieties and hybrids. The range of the genus is from the S. United States to Chili and Brazil, but it attains its greatest specific diversity in Mexico.

§ 1. Low cespitose perennials, shrubby at the base and many-stemmed: stems (or perhaps better subsimple branches) erect, crowded, or fastigiate: root stout, ligneous: leaves strictly linear to acerose, often fascicled and rigidulous, mostly rather pale. — §§ *Diplothrix & Heterogyne*, Gray, l. c.

* Ligules showy, much exceeding the achenes, white or pale yellow.

+ Leaves 1-nerved.

1. Z. acerosa, GRAY. Leaves acerose, obscurely 1-nerved, much crowded, rather sharp-pointed but scarcely pungent, 6 to 8 or 10 lines long. — Pl. Wright. i. 106. *Diplothrix acerosa*, DC. Prodr. v. 611. — Hills of W. Texas, near Pecos, *Wright*, no. 324, *Thurber*, no. 125; Mexico, San Luis Potosi, *Berlandier*, no. 1343, *Parry & Palmer*, no. 440½; Coahuila, *Palmer*, nos. 577, 578.

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2. Z. pumila, Gray. Very similar to the preceding: leaves linear, flat, mostly less than half inch long, prominently 1-nerved. — Pl. Fendl. 81, Pl. Wright. i. 105, & ii. 86. — Hills, W. Texas, *Wright*, nos. 323, 1215, to Arizona, Camp Grant, *Palmer*, no. 122, near Tucson, *Greene*, no. 1106, Camp Lowell, *Pringle*, *Lemmon*, nos. 91, 92, near Sta. Catalina, *Lemmon*, no. 3033, Lowell Mts., *W. F. Parish;* Mexico, on high plains near San Juan de la Vequeria and at "Castaniola" (= Castanuela?), *Gregg*, no. 279; on llanos of Sonora, *Schott;* east of Guadalupe Cañon, *E. K. Smith;* near Carneros Pass, Coahuila, *Pringle*, no. 2390 (distrib. as *Z. acerosa*); San Luis Potosi, *Schaffner*, no. 336, and *Parry & Palmer*, nos. 439, 440. The technical distinctions between this and the preceding are unsatisfactory at best, although the specimens are for the most part pretty readily distinguished upon the foliar differences.

\+ \+ Leaves 3-nerved.

3. Z. juniperifolia, Gray. Leaves somewhat longer than in the related species, the larger ones inch or more in length, usually whitish beneath: rays oblong, mostly 2 or even 3 times as long as broad, of deep orange color. — Pl. Wright. i. 105. *Diplothrix juniperifolia*, DC. Prodr. v. 612. — North Mexico, mountains near San Juan de Vanegas, *Berlandier*, 1359; without locality, *Gregg*, no. 68; Santillo, *Parry*, no. 40, and near same locality, *Palmer*, no. 576; and on limestone hills, Carneros Pass, *Pringle*, no. 2404.

4. Z. grandiflora, Nutt. Leaves less than an inch in length: rays pale or sulphur yellow, very broad, suborbicular in outline. — Nutt. in Torr. & Gray, Fl. ii. 298; Torr. in Emory, Report Reconn. Calif. t. 4. — Colorado, on bluffs near Pueblo, *Greene*, to W. Texas, *Wright*, nos. 322, 1213, *Pope*, Ft. Davis, *Girard;* New Mexico, *Fendler*, no. 400, near Santa Fé, *Wislizenus*, no. 415; Arizona, near Ft. Whipple, *Coues & Palmer*, no. 2821, Ft. Apache, *Palmer*, no. 583, Mustang Mts., *Pringle*, Huerfano, *Parry*, no. 106, Upper Canadian River, *Emory;* Sonora, *Thurber*, no. 312, *Smith;* San Cedro, *Lloyd*, no. 401.

* * Ligules almost obsolete, shorter or scarcely longer than the achenes.

5. Z. anomala, Gray. Scabrous-pubescent: leaves 9 lines to inch in length, line to line and a half in breadth: heads 3 to 5 lines in diameter, appearing discoid or with evident but short yellow rays: disk-flowers apparently orange-red; the limb velvety-margined. — Pl. Wright. i. 106. — Prairies of W. Texas. *Wright*, nos. 325, 1216; near Saltillo, Coahuila, Mexico, *Palmer*, no. 581. First coll. (acc. to Gray, l. c.) by *Berlandier* in Northern Mexico.

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§ 2. Erect or procumbent herbs, sometimes a little woody at the base; stems and branches loosely spreading; leaves linear, lance-linear, or elliptic-oblong: rays rather short, suborbicular or quadrate to oblong, 2 to 6 lines in length, white or sulphur yellow.

* Achenes with interrupted callous margins and somewhat tufted ciliation: slender erect annual with small heads and very pale or bright white rays.

6. Z. bicolor, Hemsl. Becoming a foot or so in height: leaves linear to lance-oblong, an inch to inch and half long, 1 to 4 lines broad, obtuse. — Biol. Cent.-Am. Bot. ii. 153, as to syn., but not as to specimens cited, except that of *Mendez*. *Z. maritima*, Gray, Proc. Am. Acad. xxii. 423, in part. *Mendezia bicolor*, DC. Prodr. v. 533; Deless. Icon. iv. t. 29. — West of Guanajuato, *Mendez;* San Luis Potosi, *Schaffner*, no. 337; Jalisco, at Tequila, *Palmer*, no. 355, and on slopes of cañons near Guadalajara, *Pringle*, no. 2313. The last two distributed as *Z. maritima*, from which this erect white-rayed plant of the inland is amply distinct.

* * Achenes evenly margined and regularly ciliated; rays yellow or orange.

7. Z. Greggii. Slender pubescent herb, becoming scabrous, erect or decumbent merely at the base: leaves linear or nearly so, 1–3-nerved, sessile: heads slender-peduncled, terminating the spreading nearly naked branches, these bearing mostly only a single pair of linear leaves: rays varying from very short-oblong to half inch in length: disk-flowers orange; ray-flowers pale yellow; ray-achenes about a line in length: disk-achenes bearing a single slender awn. — *Z. bicolor*, Hemsl. l. c. as to plants of *Coulter* and of *Seemann*, but not as to syn. *Z. maritima*, Gray, Proc. Am. Acad. xxii. 423, as to narrow-leaved form, not HBK. — Mexico, without locality, *Gregg*, 1848–1849, no. 1082; also *Baites;* W. Mexico, *Seemann;* none of these specimens show the base perfectly, but a plant apparently identical, collected by *F. H. Lamb* on plains at Zopelote, Tepic, 9 February, 1895, no. 555, has a thickish perennial root.

8. Z. littoralis. Procumbent spreading herb, probably of biennial or perennial duration: stems leafy, branched, striate, puberulent: leaves elliptic-oblong or elliptic-lanceolate, obtuse or obtusish at both ends, 3 (or obscurely 5)-nerved and reticulated, green on both sides, 4 to 10 lines long, a third to half as broad: heads scarcely peduncled, borne at the ends of leafy branches: rays orbicular or nearly so, pale yellow, striate and greenish toward the ends beneath: disk-flowers bright orange-colored; chaff oblong, very obtuse or truncate: achenes with a very narrow cartilaginous margin, ciliated: pappus of a single awn with or without a shorter second one: achenes of the ray-flowers about 1½ lines long, tuberculate. — Collected at Mazatlan by *Th. Coulter*, and redis-

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covered on dry hills of the coast at the same point by *W. G. Wright*, January, 1889, no. 1201 (distributed as *Z. maritima?*); also by *F. H. Lamb* on dry rocky cliffs at same place, 26 December, 1894, no. 325 (distributed as *Z. maritima*). In the presence of good material of all three species we cannot doubt the complete distinctness of this species from the preceding and from the following.

§ 3. Herbs with ovate or elliptic-oblong leaves: heads strongly bicolorous; disk dark purple-brown, nearly black; rays oblong, bright yellow.

9. Z. maritima, HBK. Prostrate, much branched from the base: stems spreading: leaves elliptic or elliptic-oblong, obtuse at the apex, rather abruptly contracted to short but distinct pubescent petioles: heads 8 to 10 lines in diameter (incl. rays), terminal, mostly borne on long naked peduncles: chaff narrowed above although obtusish at the dark-colored point; achenes of the disk-flowers strongly callous-margined: rays oblong, golden yellow; ray-achenes 1½ to 2 lines long. — Nov. Gen. & Spec. iv. 251, not Gray, l. c. — Acapulco, *Humboldt & Bonpland;* rediscovered at the same point by *Palmer*, February, 1895, no. 523. From its peduncled heads, oblong rays, callous-margined achenes, etc., we cannot doubt that Dr. Palmer's plant represents the real *Z. maritima* which came from the same locality so long ago. Yet Palmer's plant has leaves considerably larger than those described by Kunth.

10. Z. Palmeri, Gray. Erect branched annual, a foot or so in height: leaves ovate, or lanceolate from an ovate cordate or subcordate closely sessile base, acute or acuminate at the apex. — Proc. Am. Acad. xxii. 423. — Jalisco, at Tequila, *Palmer*, no. 386, *Pringle*, no. 4557; also at Manzanillo, *Palmer*, no. 893, and Colima, *Palmer*, no. 893 a.

§ 4. Erect perennials with spreading branches and narrow linear or oblong leaves: rays oblong, 4 to 12 lines in length, deep orange-colored as well as the disk-flowers.

11. Z. linearis, Benth. Much branched, 8 inches to a foot or two in height: heads many and very showy, of intense orange color (persisting even in old dried specimens): leaves linear or nearly so. — Pl. Hartw. 17. — Aguas Calientes, *Hartweg*, no. 117; San Luis Potosi, near Morales, *Schaffner*, no. 210, and in same state by *Parry & Palmer*, no. 441; Jalisco, on the Rio Blanco, *Palmer*, no. 54, and on hills near Guadalajara, *Pringle*, no. 1778.

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Var. latifolia, Rose. Leaves somewhat broader, oblong. — Contrib. U. S. Nat. Herb. i. 102. — Alamos, *Palmer*, no. 352.

§ 5. Distinctly annual herb with showy flowers: disk and rays concolorous, yellow, red, or purple, or if discolorous the disk-flowers yellow or greenish and the rays red or purple: leaves ovate, lanceolate, or elliptic.

* Leaves sessile or nearly so, entire.

+ Achenes of the disk-flowers short and broad, obovate, 2 to 2½ lines in length: stems hirsute with spreading hairs.

12. Z. angustifolia, HBK. Branching, 1½ to 2 feet high: leaves lance-linear from a sessile ovate base: disk very convex, orange-yellow from the abundant acute exserted chaff (orange-yellow minutely tipped with purple at the very summit); disk-flowers at first orange and becoming darker with age: rays paler yellow. — Nov. Gen. & Spec. iv. 251; DC. Prodr. v. 536. — Originally collected in the neighborhood of Guanajuato by *Humboldt & Bonpland*, and described as having leaves "scarcely 2 lines broad." Our only authentic specimen of this species is one of *Mendez* sent by De Candolle to Dr. Gray and mentioned in the Prodromus as of this species. From other details of the description we cannot doubt that De Candolle was right in referring this plant to Kunth's species, although in it and in all the following specimens attributed to this species the leaves are considerably broader than originally described, varying from 3 to 8 lines in breadth. Evidently identical with Mendez' plant are specimens collected at Morelia, *Ghiesbreght;* no. 369 (?*Z. Ghiesbreghtii*, Verlot, Rev. Hort. 1862, 368; Vilmorin, Fl. Pl. Terre, 971, = *Z. Mexicana*, Hort. *fide* Vilmorin, l. c.), and near La Barca, Jalisco, *Pringle*, no. 3866; also cultivated plants from the Harvard Botanic Garden, dated 1861 and 1865. From this species, notwithstanding its still broader leaves, we cannot confidently separate the horticultural *Z. Haageana*, Regel, Gartenfl. x. 355, *ex char.*

13. Z. elegans, Jacq. Erect: stems less branched: leaves broader, ovate or elliptic, closely sessile and clasping, inch or so in breadth: disk-flowers yellow or orange, scarcely or not at all exceeded by the purplish tipped chaff; rays numerous, purple or lilac. — Coll. & Icon. Pl. Rar. iii. t. 589; Sims, Bot. Mag. t. 527. — South Mexico, Ziticuaro, *Hartweg;* mountains of Tixtla near Cuernavaca, *Berlandier*, no. 975; also without locality, *Ghiesbreght*, no. 306. Extensively cultivated in various countries.

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+ + Achenes longer, narrower, oblong, 3 or 4 lines in length.

++ Hirsute with spreading hairs: rays rather broad, patulous, yellow as well as the disk.

14. Z. pauciflora, L. Erect roughish-pubescent annual, somewhat corymbosely branched above: peduncles at maturity enlarged upwards and fistulous: the yellow heads about an inch in diameter. — Spec. ed. 3, 1269; Lam. Ill. t. 685, f. 1; DC. Prodr. v. 535. *Z. lutea*, Gærtn. Frucht. ii. 459, t. 172. — Chiapas, Mexico, *Nelson*, no. 3074; Andes of Peru, *Mathews*, no. 456, and Bolivia, *Mandon*, no. 38; also St. Thomas, W. I., *Eggers*, no. 400. Introduced in W. Africa at Cape Verd.

++ ++ Pubescence of the stem much finer, appressed or very rarely spreading: rays red or purple, mostly narrow and suberect or scarcely spreading.

15. Z. multiflora, L. l. c. Erect annual with habit of the preceding, or subsimple: leaves ovate and acute or ovate-oblong and obtusish: peduncles (frequently short or none) often thickened upwards. — L. f. Dec. Ups. 23, t. 12; Curtis, Bot. Mag. t. 149. *Z. tenuiflora*, Jacq. Icon. Pl. Rar. iii. 590. *Z. leptopoda*, DC. Prodr. v. 535 (merely weak form or state with more slender peduncles). *Z. Floridana*, Raf. New Fl. iv. 70. *Z. intermedia*, Engelm. in Wisliz. Tour N. Mex. 107. *Z. Mendocino*, Philippi, Sert. Mendoc. Alt. 27, *fide* Baker, Fl. Bras. vi. pt. 3, 178. — The commonest and most widely distributed species extending from Florida, *Chapman*, *Curtiss*, no. 1417, to Texas, *Drummond*, no. 115, *Lindheimer*, no. 93 (but in these localities probably introduced; see Gray, Syn. Fl. i. pt. 2, 253); S. Arizona near Ft. Huachuca, *Lemmon*, no. 2761; throughout Mexico, Sonora, *Wright*, no. 1213, *Thurber*, no. 920, *Schott*, *Hartman*, no. 104; Chihuahua, *Thurber*, no. 832, *Schott*, *Wislizenus*, *Palmer*, nos. 115, 156, *Pringle*, no. 316; Coahuila, *Palmer*, nos. 574, 575; San Luis Potosi, *Parry & Palmer*, no. 438; Orizaba, *Bourgeau*, no. 1682, *Botteri*, nos. 73, 516, 940, *Seaton*, no. 345; Cordova, *Bourgeau*, no. 1633; Guadalupe, *Bourgeau*, no. 500; Oaxaca, *Andrieux*, no. 314, *L. C. Smith*, nos. 813, 957; Chiapas, *Ghiesbreght*, no. 126; Guatemala, *Heyde & Lux* (no. 3808 of Donnell Smith's sets); Venezuela, *Fendler*, no. 1974; Bolivian Andes, *Mandon*, nos. 39, 40, and *Bang*, no. 207.

The yellow-rayed specimens, referred by various authors to this species, have in most instances, if not always, the pubescence of *Z. pauciflora*, to which it seems best to refer them.

* * Leaves elliptic, petiolate, dentate.

Z. Liebmannii, Benth. & Hook. f. Leaves squamulose-hirsute above, ferrugineous beneath: peduncles quadrangular-sulcate: chaff

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aculeate or uncinate. — Benth. & Hook. f. acc. to Klatt, Leopoldina, xxiii. 2, where first described. — Mexico on the Rio Taba, *Liebmann*, no. 552.

Doubtful species known chiefly or exclusively from cultivated specimens.

Z. RŒZLII, Hort. Gard. Chron. 1872, page 1392; Hook. f. & Jackson, Ind. Kew. ii. 1251, is a mere horticultural name for a yellow-flowered annual species said to come from Mexico, but never properly described.

Z. VERTICILLATA, Andrews, Bot. Rep. iii. t. 189, is apparently only a robust cultivated form of *Z. multiflora*, with verticillate leaves, and double series of rays: said also to come from S. Mexico.

Z. HYBRIDA, Römer & Usteri, Mag. Bot. St. 1 (1787), 49; Curtis, Bot. Mag. t. 2123 (*Z. grandiflora*, Hort. *fide* DC. Prodr. v. 536, not Nutt.), is an annual with deep red rays, greenish disk, and chaff not fringed at the apex: apparently only a form of *Z. multiflora*, with rays becoming broad and somewhat double by cultivation.

Z. AMBIGUA, Salm-Dyck, and Z. DISCOLOR, Hort., are names only, and wholly obscure.

IV. — REVISION OF THE MEXICAN AND CENTRAL AMERICAN SPECIES OF THE GENUS CALEA.

CALEA, L., R. Br. (Name of obscure origin. The derivation from καλός, beautiful, is unsatisfactory, and at best very doubtful.) — Heads mostly small or of medium size, radiate or discoid. Involucre ovoid, cylindrical, or campanulate; its scales pluriseriate, imbricated, usually very unequal, the outer gradually shorter, all scarious or the outer (rarely all) herbaceous or herbaceous-tipped. Receptacle small, convex, or flattish, paleaceous: chaff scarious, concave, rigid or thin and hyaline. Ray-flowers when present fertile; ligules yellow, white, or roseate, entire or denticulate at the apex. Disk-flowers fertile, yellow or white; the limb of the corolla regular, deeply 5-cleft. Anthers appendaged at the apex and shortly sagittate-lobed at the base. Style-branches subtruncate or with a very short appendage. Achenes slender, subterete or more or less distinctly 4–5-angled, usually pubescent: pappus of 4 to 20 subequal scales; these mostly fringed or ciliolate, rarely wanting, when numerous narrow and acuminate or when fewer usually short and blunt. — About 85 species of shrubs and perennial herbs (rarely climbers), extending from Mexico to Tropical S. America. Leaves opposite, simple, mostly ovate, oblong, or lanceolate, sessile or petiolate, mostly

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serrate or dentate, rarely entire (in one or more S. American species pinnatifid). The limits of the genus here taken are essentially those of Bentham & Hooker (Gen. ii. 390), and Hoffmann (in Engl. & Prantl, Nat. Pflanzenf. iv. Ab. 5, 246), whose generic synonymy need not here be repeated. The Mexican and Central American species may be subdivided according to the following characters.

Subgenus 1. LEONTOPHTHALMUM, Benth. & Hook. f. Heads very large (inch or more in diameter), radiate, few or solitary, long-peduncled: scales of the involucre few-seriate, broad, the outer often herbaceous: both disk- and ray-flowers yellow: scales of the pappus numerous. — Gen. ii. 391. *Leontophthalmum*, Willd. Gesellsch. Natur. Fr. Berl. Mag. 1807, 40; HBK. Nov. Gen. & Spec. iv. t. 409. — Mostly S. American species, only the following known from Mexico.

1. C. megacephala. Erect, herbaceous, 2 or 3 feet high: stem striate-angulate, hirsute-pubescent, leafy to the middle and terminating in one or (more rarely) three long naked 1-headed peduncles (often 18 inches in length): leaves thin, ample, hirsute upon both sides, rhombic-ovate or with deltoid acute or obtusish coarsely dentate blade (3 to 4 inches long, nearly as broad) abruptly contracted at the base, then gradually attenuate into a winged entire petiole of nearly equal length; the lowermost leaves smaller, obovate, and with rounded apex: heads, exclusive of rays, 9 to 12 lines in diameter: flowers deep orange; ray-flowers 15 to 20, with oblong spreading ligules half inch in length: disk conical. — Collected by *E. W. Nelson* at Sta. Efigenia, Oaxaca, altitude 500 feet, 18 July, 1895, no. 2844, and on top of ridge back of Tonala, Chiapas, altitude 1,200 to 2,500 feet, 10 August, 1895, no. 2884. A plant without close affinities in the Mexican species of the genus, but related to several of the S. American.

Subgenus 2. OTEIZA, Llav. (as gen.). Heads few or solitary, large, 9 to 15 lines in diameter, loosely cymose or (in *C. elegans*) somewhat densely grouped at the ends of the branches: rays long (nearly or quite half inch in length) white or roseate: leaves sessile or nearly so.

* Leaves oblong, narrowed at the base.

2. C. Palmeri, Gray. Herbaceous, erect or slightly decumbent: stem simple or divided almost from the base, pubescent, 18 inches to 2 feet high: leaves 2 to 3 inches long, 4 to 6 lines broad, denticulate and ciliated, 3-nerved: heads 1 to 9, in terminal loose cymes; slender peduncles nearly naked; the floral leaves short and linear: involucral bracts green, few-seriate and more nearly equal than is usual in the genus. — Proc. Am. Acad. xxii. 430. — On the Rio Blanco, Jalisco, *Palmer*, no.

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147; on slopes of a barranca near Guadalajara, *Pringle*, no. 2904; and Michoacan, on grassy hills near Patzcuaro, *Pringle*, no. 4125; fl. July.

* * Leaves ovate, abrupt or cordate at the sessile or subsessile base.

3. C. elegans, DC. Leaves thickish, quite glabrous above, finely pubescent upon the veins beneath, ovate to ovate-lanceolate, few-toothed, long-acuminate, considerably paler beneath: heads loosely or somewhat closely cymose at the ends of the branches: rays about 8 or 10. — Prodr. v. 674. *Oteiza acuminata*, Llav. Reg. Trim. Mex. 1832, 41. — Valley of San Luis Potosi, *Schaffner*, no. 237, and *Parry & Palmer*, no. 491; and in Tultenango Cañon, State of Mexico, *Pringle*, no. 4297, with heads more aggregated; fl. August till last of October. An imperfect specimen collected by *Baites*, 1846, in Mexico, without more precise locality, is probably of this species.

4. C. multiradiata, Seaton. Herbaceous, erect or decumbent, with habit of the preceding but with sessile leaves thinner, less attenuate, appressed-pubescent upon both surfaces and scarcely paler beneath: heads on very long peduncles, 3 or 4 in number: rays 15 to 20. — Proc. Am. Acad. xxviii. 120. — Wooded slopes of Mt. Orizaba, altitude 10,000 feet, *Seaton*, no. 167, in part. In flower in August. With the type material of this species in the Gray Herbarium were associated specimens of a *Sabazia* and *Tridax* of similar habit.

5. C. sabazioides, Hemsl. "Slender herb, 1 to 1½ feet high, procumbent, rooting at the base, in habit very similar to *Sabazia sarmentosa:* leaves decussate, ovate, petiolate, acute, crenate, 3-nerved, hirsute: heads solitary, radiate, as large as in *Tridax:* bractioles [chaff] scarious, uninerviate, pale fuscous, oblong-ovate, 2-dentate beneath the gradually and narrowly acuminate summit: rays purplish white." — Biol. Cent.-Am. Bot. ii. 206. *Allocarpus sabazioides*, Less. Linnæa, ix. 590. — Near San Miguel del Soldado and La Joya, S. Mexico. No specimens exactly agreeing with this description have been seen by the writers, and the characters are here translated from the Latin of Lessing.

Subgenus 3. EUCALEA. Benth. & Hook. f. (extended). Heads relatively small and numerous, in close corymbs or somewhat umbellate: rays short or none: scales of the pappus 7 to 20: leaves sessile or short-petioled, serrate or dentate (in one species subentire). — Gen. ii. 391.

* Inflorescences terminal, close, on long naked peduncles: upper leaves reduced to small oblong or linear bracts: heads homogamous: pappus often reduced or wholly wanting. — *Calydermos*, Lag.

+ Scales of the involucre densely fringed with yellowish glandular-tipped hairs.

6. C. thysanolepis. Slender erect herb, 18 inches to 2 feet high: stem simple, striate, densely pubescent, prolonged at the summit into a

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nearly naked peduncle bearing a dense cymose cluster of heads: leaves ovate, acute, subcordate at the base, sharply dentate, roughish-pubescent upon both surfaces, 3–5-nerved and coarsely reticulate-veined, 1 to 3 inches long, a third or half as broad, scarcely paler beneath, closely sessile: inflorescence and especially the margins of the 3-seriate involucral scales densely glandular-pubescent: heads about 18-flowered: chaff irregularly erose, often constricted below the summit: achenes calvous, terete: corolla pubescent. — Collected by *E. W. Nelson* on the summit of the Sierra Madre near Chilpancingo, Guerrero, altitude 9,000 to 10,200 feet, in flower 24 December, 1894.

+ + Scales of the involucre essentially glabrous.

7. **C. peduncularis**, HBK. Erect or decumbent, 1 to 2 feet high, pubescent and usually more or less scabrous: leaves ovate, closely sessile by a broad abrupt or subcordate base, dentate, 1½ to 3 inches long, nearly half as broad: scales of the involucre yellow: pappus present, about two thirds the length of the achenes. — Nov. Gen. & Spec. iv. 295, t. 408. *Calydermos peduncularis*, DC. Prodr. v. 669. *C. scaber*, Lag. Nov. Gen. 25. *Calebrachys peduncularis*, Cass. Dict. Sci. Nat. lv. 277. — South Mexico, Mt. Jorullo, at 3,000 feet, *Humboldt & Bonpland;* Mirador, *Sartorius;* Chiapas, *Ghiesbreght*, no. 783, and *E. W. Nelson*, no. 3261; mountains near Guapimalpatt, Mexico, *Schaffner*, no. 35; Chinantla, *Liebmann*, no. 413; Boerego near Orizaba, *Bourgeau*, no. 3149; Mt. Orizaba, altitude 4,000 feet, *Seaton*, no. 126, and altitude 10,000 feet by same collector, no. 168; also in Orizaba, *Hahn*, no. 2692, *Bilimek*, no. 544, and *Botteri*, nos. 620, 803; Jalapa, *Th. Coulter*, no. 334. in part.

Var. **epapposa**, HBK. Closely similar in foliage and habit: achenes wholly destitute of pappus. — HBK. *fide* DC. Prodr. v. 669. — Near Santa Rosa, acc. to HBK. l. c.; also San Luis Potosi, *Parry & Palmer*, no. 497; Las Canoas in the same state, *Pringle*, no. 3672; Valley of Mexico near the Santa Fé, *Bourgeau*, no. 718; Jalapa. *Th. Coulter*, no. 334, in part, and near Reyes, Oaxaca, altitude 6,700 to 10,000 feet, *E. W. Nelson;* also Mexico without locality, *Th. Coulter*, no. 250, in part (the other part of the same number being a *Eupatorium*); fl. August to October.

Var. **longifolia**, (Lag.) Gray. Leaves lanceolate or lance-oblong, opposite or ternate, relatively much narrower and more elongated; the lower 3 to 6 inches long: scales of the involucre yellow: pappus none. — Proc. Am. Acad. xxii. 430, as to syn. *Calydermos longifolius*, Lag. and Pl. Hartw. *Calydermos scaber*, var. Benth. Pl. Hartw. 346. — Bolaños, *Hartweg*, no. 122, at least as to long-leaved specimens.

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Var. livida. Leaves narrow, lanceolate to lance-oblong, very scabrous-pubescent: involucral scales dark purple: pappus present. — *C. peduncularis*, var. *longifolia*, Gray, as to pl. Palmer. — On the Rio Blanco, Jalisco, *Palmer*, no. 317; and in damp shady cañons near Guadalajara, *Pringle*, no. 2326; fl. August to October.

8. C. Liebmannii, Schz. Bip. Branches terete: leaves petiolate, ovate-elliptic, 2 inches long, 9 lines broad, coriaceous, 3-nerved, glabrous above, ferrugineous and chrysopunctate beneath: heads short-pedicelled, 6-flowered, disposed at the summits of the peduncles in umbelliform corymbs: involucres cylindraceous: scales 3-seriate, ovate, subreflexed at the apex: chaff membranaceous, ovate, acute: achenes glabrous; scales of the pappus 10, short. — Leopoldina, xxiii. 6. — Gualulu, *Liebmann*, no. 411. Not seen by the writers, and doubtfully referred to this subdivision. The characters are drawn from the original description of Klatt.

* * Inflorescences more numerous, short-peduncled or sessile, together forming leafy panicles.

+ Pappus-scales rather few, ovate to lanceolate, shorter than the achenes.

++ Inflorescences lax, somewhat umbelliform: pedicels slender and relatively long, most of them considerably exceeding the heads in length.

9. C. salmeæfolia. Hemsl. l. c. Shrub, 2 to 3 feet high, with rhombic-ovate leaves acute at both ends, smoothish and lucid above, 1 to 1½ inches long, half as broad: heads 8–14-flowered. — *Calydermos salmeæfolius*, DC. Prodr. v. 670. — Between Tula and Tampico, Tamaulipas, *Berlandier*, nos. 718, 2135.

++ ++ Inflorescence denser: pedicels mostly very short, seldom equalling or exceeding the heads (except in *C. Zacatechichi*, var. *macrophylla*).

= Involucre of most or all of the heads closely subtended by a few broad obtuse herbaceous bractlets.

10. C. albida. Gray. A branching pubescent shrub: leaves ovate, shortly petiolate, serrate, acutish at the apex, abruptly contracted at the broad obtuse base, scabrous above, somewhat paler and moderately pubescent below, 1 to 1½ inches long, two thirds as broad: heads numerous, cymosely clustered at the ends of the leafy branches, on pedicels 1 to 9 lines in length, homogamous or with one or more reduced ray-flowers; flowers whitish: achenes pubescent, scales of the pappus acute. — Proc. Am. Acad. xv. 38. — San Luis Potosi, in mountains near Morales, *Schaffner*, no. 269, and later in the same state, *Parry & Palmer*, no. 448; in fl. in August.

11. C. hypoleuca. Similar in habit: leaves somewhat larger, broadly ovate or suborbicular, sessile or very shortly petioled, scabrous

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above, densely tomentose and canescent beneath, 1½ to 2 inches in diameter: heads very short-pedicelled or subsessile: scales of the pappus obtuse or rounded at the summit. — Oaxaca, Sierra de San Felipe, altitude 6,000 feet, 7 September, 1894, *Pringle*, no. 5784; dry hills in the Valley of Oaxaca, altitude 5,100 to 5,800 feet, 8 September, 1894, *E. W. Nelson*, no. 1217, and in neighboring locality without date, *Nelson*, no. 1192; also in Valley of Etla, September, 1895, *Alvarez*, (L. C. Smith's) no. 766.

= = Involucre nearly or quite naked, without subtending herbaceous bractlets, or these small and scattered, lanceolate or subulate.

a. Leaves wholly glabrous, quite smooth and free from resinous dots or globules.

12. C. Nelsonii. Glabrous, copiously branched and very leafy: leaves rhombic-ovate, coarsely and rather bluntly toothed, 3-nerved, short-petioled, paler beneath, quite smooth but scarcely or not at all lucid upon both sides, 1½ to 2 inches long, half as broad: heads very numerous in many terminal or subterminal close cymes, together forming a considerable pyramidal inflorescence: involucral bracts light colored, striated, obtuse: disk-flowers about 7; ray-flowers 2 or 3, with very short obscure ligules: pappus of about 12 scales. — Collected by *E. W. Nelson* on the top of ridge back of Tonala, Chiapas, altitude 1,200 to 2,500 feet, 10 August, 1895, no. 2887.

b. Leaves pubescent, or at least covered on the lower surface with resinous atoms.

13. C. Zacatechichi, Schlecht. Much branched shrub with harsh scabrous foliage: leaves rhombic-ovate to ovate-oblong, short-petioled, described as deeply crenate, but more often serrate-dentate, acute, cuneate at the base: heads about 12-flowered, very short-pedicelled or sessile in numerous small terminal cymes: scales of the involucre with scarious and undulate margins. — Linnæa, ix. 589; DC. Prodr. v. 672; Hoffm. in Engl. & Prantl, Nat. Pflanzenf. iv. Ab. 5, 246, f. 120, A–C. — On hills near Hacienda de la Laguna and Jalapa, *Schiede;* Mirador, *Sartorius;* Orizaba, *Botteri*, nos. 481, 488; San Pedro Sula, Dept. Sta. Barbara, Honduras, *Thieme* (no. 5300 of Donnell Smith's sets, a form approaching var. *macrophylla*), and Guanagaza, Dept. Sta. Rosa, Guatemala, *Heyde & Lux* (no. 6159 of same sets). The leaves are reputed a remedy for cholera. A form probably of the same species, but having the involucral bracts less scarious-undulate and more often ciliolate, has been collected on hills near Guadalajara, by *Palmer*, no. 352, and *Pringle*, no. 2475. Another form collected by *Pringle* in the Sierra Madre near Monterey, Nuevo Leon, no. 2224, differs only in

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having the involucre calyculate with 1 to 3 lanceolate herbaceous-tipped bractlets.

Var. rugosa. Habit, foliage, and inflorescence of the preceding species: heads smaller, 5–10-flowered. — *C. rugosa*, Hemsl. Biol. Cent.-Am. Bot. ii. 206. *Calydermos rugosus*, DC. Prodr. v. 670. — Cuernavaca, Morelos, *Berlandier*, no. 1061; also in Orizaba, *Bourgeau*, no. 3095; near Acapulco, *Palmer*, no. 52.

Var. macrophylla. Leaves mostly much larger, $2\frac{1}{2}$ to 3 inches or more in length, half as broad, less rugose: pedicels often equalling or considerably exceeding the 12-flowered heads: achenes nearly $1\frac{1}{2}$ lines in length, the pappus only a third as long. — Collected by *H. von Tuerckheim* at Coban, Dept. Alta Verapaz, altitude 4,300 feet, February, 1888, and distributed as *C. Zacatechichi* in Donnell Smith's Guatemalan sets, no. 1345; also by *Heyde & Lux*, at Laguna de Ayarza, Dept. Jalapa, altitude 8,000 feet, distributed in same set as *C. salmeæfolia*, no. 3782.

+– +– Scales of the pappus narrower, more numerous, equalling or exceeding the achenes.

–+ Involucre cylindrical, or narrowly campanulate, rather few-flowered; scales broad, scarious, glabrous or only the outermost herbaceous and somewhat pubescent: pedicels less than an inch in length: plants pubescent.

= Heads numerous, radiate, with ligules evident.

a. Inflorescences terminal, cymose-paniculate or somewhat corymbose: heads very numerous, small: involucre ecalyculate.

14. C. integrifolia, Hemsl. Shrub, 4 to 8 feet high: leaves ovate-lanceolate, attenuate at the apex, rounded or obtusish at the short-petioled base, cuspidate-denticulate, varying from papillose-pubescent and very scabrous to smoothish and lucid, 2 to $4\frac{1}{2}$ inches long, a third to half as broad; the veins very prominent beneath: heads 15–20-flowered: disk-flowers yellow; ray-flowers 5, white, destitute of pappus. — Biol. Centr.-Am. Bot. ii. 205. *Allocarpus integrifolius*, DC. Prodr. v. 676. — Originally collected in Mexico without more exact locality by *Karwinski*; later in Mirador by *Sartorius*, by *Liebmann*, no. 418, and by *E. W. Nelson*, no. 86; Chiapas, *Ghiesbreght*, no. 565; Cordova, *Bourgeau*, no. 1751, and *A. Gray*; near Orizaba, altitude 4,000 feet, *Pringle*, no. 5915, and *E. W. Nelson*, no. 2; Oaxaca, on the Sierra de San Felipe, altitude 8,000 feet, *Pringle*, no. 6111; Cieneguilla, *L. C. Smith*, no. 381; between Panixtlahuaca and Jaquila, altitude 1,000 to 5,000 feet, *E. W. Nelson*, no. 2389; City of Mexico, *Mrs. D. H. Sheldon*; Guatemala, at Coban, Dept. Alta Verapaz, altitude 4,300 feet, *von Tuerckheim* (no. 379 of Donnell Smith's sets); Guarda Viejo, Dept. of Guatemala, altitude

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5,000 feet, *Donnell Smith*, no. 2345; Teocinte, Dept. Sta. Barbara, altitude 2,500 feet, *Heyde & Lux* (no. 4199 of Donnell Smith's sets); San Rafael, Dept. Zacatepequez, altitude 6,500 feet, *Donnell Smith*, no. 2332. One of the commonest species of S. Mexico and Central America.

Var. dentata, Coulter. Leaves with more pronounced dentation, long caudate-acuminate: the floral oblong-linear, attenuate. — Bot. Gaz. xx. 51. — Nebaj, Dept. Quiche, Guatemala, altitude 7,000 feet, *Heyde & Lux* (no. 4506 of Donnell Smith's sets). Hither we would refer *Nelson's* no. 2513, collected between Suchiotepec and Miahuatlan, Oaxaca.

b. Inflorescences cymose-umbellate in the upper axils, together forming a leafy elongated or thyrsoid panicle: involucre commonly calyculate with one or more herbaceous bractlets.

15. C. axillaris, DC. Shrub: leaves ovate-lanceolate or ovate-oblong, attenuate-acuminate, sharply serrate. — Prodr. v. 673. *Mocinna serrata*, Lag. Nov. Gen. 31. — Mexico, *Hænke;* Valley of Cordova, *Bourgeau*, no. 1675; between San Luis Potosi and Tampico, *Palmer*, no. 1111. Passes into

Var. urticæfolia. Leaves shorter and relatively broader, ovate, acute or acutish to barely acuminate, crenate-serrate. — *Caleacte urticifolia*, R. Br. Trans. Linn. Soc. xii. 109. *Calea urticæfolia*, DC. l. c. 674. — The commoner form, Mexico without locality, *Gregg*, nos. 1002, 1042; Orizaba, *Schaffner*, and *A. Gray;* Wartenberg near Tantoyuca, Huasteca, *Ervendberg*, no. 96 (passing to typical form); Colima, *Palmer*, no. 1215; Jalisco, on rocky slopes near Guadalajara, *Pringle*. no. 1788; and in neighboring locality on Rio Blanco, *Palmer*, no. 675 (robust form with ternate leaves); Guatemala on the Rio Amatitlan. altitude 3,900 feet, *Donnell Smith*, no. 2337, also Jumaytepeque, Dept. Santa Rosa, altitude 6,000 feet, *Heyde & Lux* (no. 3790 of Donnell Smith's sets); Costa Rica at Navarro, altitude 3,500 feet, *Donnell Smith*, no. 4857; Nicaragua, *Wright*.

= = Heads subumbellate at the ends of the branches or from the upper axils, discoid: Chiapas and southward.

16. C. prunifolia, HBK. Shrub: leaves broadly elliptic-ovate, crenate, obtuse, abruptly contracted to a subcuneate base, slender-petioled, scabrous and rugose above, somewhat paler and scabrous beneath, 2 to 3½ inches long, two thirds as broad: heads about 18-flowered. — Nov. Gen. & Spec. iv. 294, t. 406. — A South American species reaching the Isthmus of Panama, where collected by *Seemann* and later by *Hayes*.

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17. C. trichotoma, Donnell Smith. Densely fuscous-tomentose: leaves ovate, acutish, crenate-serrate, scabrous above, somewhat canescent-tomentose beneath, 1 to 2¼ inches long, one half to two thirds as broad; stems somewhat tortuous as though scandent. — Bot. Gaz. xiii. 299. — Rocky mountain sides near Coban, Dept. Alta Verapaz, altitude 4,300 feet, *von Tuerckheim* (no. 1353 of Donnell Smith's sets); Chiapas, table land about Ocuilapa, altitude 3,400 to 3,800 feet, *E. W. Nelson*, no. 3004.

↔ ↔ Heads campanulate, many-flowered: scales of the involucre glabrous: leaves very large (2½ inches or more in breadth): pedicels less than an inch in length: Costa Rican species.

18. C. pellucidinervia, Klatt. Leaves membranaceous, broadly ovate, 4 inches long, two thirds as broad, long-acuminate, serrate-dentate, rounded at the base; petiole 5 lines long, densely pilose: ligules 6, 2 lines in length. — Bull. Soc. Bot. Belg. xxxi. 207. — In woods at Terraba, altitude 900 feet, *Pittier*, nos. 3707, 3726. A species not seen by the writers; the description is condensed from the original characterization.

↔ ↔ ↔ Heads campanulate, many-flowered: scales of the involucre multiseriate, sub-herbaceous, very pubescent: pedicles half inch or less in length: leaves smaller: Mexican species.

19. C. scabrifolia, Benth. & Hook. f. Shrub: leaves ovate-oblong or oblong-lanceolate, attenuate, serrate or serrulate, thickish above papillose-pubescent and very scabrous, below sparingly pubescent, slightly paler and with veins very prominent: pedicels and involucral bracts densely canescent-tomentose: disk-flowers 125 or more; ray-flowers 20 to 25, the latter without pappus: plant drying green. — Benth. & Hook. f. acc. to Hemsl. Biol. Centr.-Am. Bot. ii. 206. *Allocarpus scabrifolius*, Hook. & Arn. Bot. Beech. 300. *Ferdinanda oppositifolia*, Schz. Bip. in Seemann, Bot. Herald (by error cited as *Zaluzania* by Benth. & Hook. f. Gen. ii. 391). *Perymenium album*, Wats. Proc. Am. Acad. xxv. 154. — N. W. Mexico in Sierra Madre, *Seemann;* Jalisco, on mountains near Lake Chapala, *Pringle*, no. 2438, in fl. December; Alamos, *Palmer*, no. 283.

20. C. submembranacea, Fernald. Similar in habit: leaves thinner, nearly smooth and somewhat lucid, somewhat nigrescent in drying. — Bot. Gaz. xx. 535. — On mountain sides, Zopelote, Tepic, altitude 3,000 feet, *Lamb*, no. 554.

↔ ↔ ↔ ↔ Heads few; campanulate: scales of the involucre broad, few-seriate, glabrous: pedicels very long (1½ to 2 inches): plant essentially glabrous.

21. C. longipedicellata. Shrub, glabrous throughout except the puberulent summits of the long pedicels: leaves elliptical, acutish at both

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ends, callous-denticulate, short-petioled, paler beneath, 3-nerved, 1½ to 2 inches long, 9 or 10 lines broad: heads 2 to 4 at the ends of the branches (springing from the opposite axils of the last pair or two pairs of leaves), half inch in diameter, homogamous: outer involucral scales scarcely shorter than the inner, broadly oblong, rounded at the apex: scales of the pappus linear-attenuate, about 20 in number: achenes glabrous. — Collected by *E. W. Nelson*, near Choapam, altitude 3,800 to 4,500 feet, 28, 29 July, 1894, no. 898.

← ← ← Doubtful and poorly characterized species, probably referable to this subdivision and very likely synonymous with some of the foregoing species.

22. C. cacosmioides, Less. "Bracteoles [by which is meant apparently the *chaff*] broad, at the apex laciniate, acuminate and aristate: involucres cylindrical, about 12-flowered: differing from *C. solidaginia*, Kunth, not only in the form of the bracteoles, but also in the radiate heads, and in the leaves obtuse at the base or acute but not acuminate into petioles, sharply serrate, subglabrous, lucid above." — Linnæa, v. 157. — In open places near Jalapa, October, *Schiede & Deppe*. The characters translated from the original Latin description.

23. C. brachiata, DC. "Shrub: branches brachiate: leaves ovate, obtusely mucronate: heads fasciculate and mostly terminal." — Prodr. v. 673 (whence descr.). *Mocinna brachiata*, Lag. Nov. Gen. 31. *Galinsogea brachiata*, Spreng. Syst. iii. 579. — "In Panamaide" acc. to Lagasca, l. c.

Subgenus 4. TETRACHYRON, Benth. & Hook. f. Heads corymbose, radiate: leaves oblong or lanceolate, often with interpetiolar dilation: both disk- and ray-flowers yellow: scales of the pappus only 4. — Gen. ii. 391. *Tetrachyron*, Schlecht. Linnæa, xix. 744.

24. C. manicata, Benth. & Hook. f., l. c. A tall glabrous shrub, 8 to 12 feet in height: leaves lanceolate, gradually narrowed at both ends, serrate, 4 or 5 inches long, 9 lines broad, nigrescent in drying: involucres somewhat turbinate-campanulate, ecalyculate: corymbs flat, 2 to 6 inches or more in diameter: rays about 12: scales of the pappus a third to half as long as the achene. — Benth. & Hook. f. acc. to Hemsl. Biol. Cent.-Am. Bot. ii. 206. *Tetrachyron manicatum*, Schlecht. l. c. — Cordillera near Vera Cruz, *Galeotti*, no. 2309; Mirador, *Liebmann*, no. 392, *Dr. Berendt*, and *E. W. Nelson*, no. 85; Orizaba. *Schaffner*, *Botteri*, no. 807; also Sierra del Borrego, above Orizaba, altitude 4,500 feet, *Pringle*, no. 6133.

25. C. Orizabaensis, Klatt. Branchlets pentagonal: lower leaves petiolate, large, 5 inches long, 3 inches wide, oblong, sinuate-undulate,

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glabrous above, pilose on the nerves beneath: heads pedicellate in lanceolate-bracted corymbs: scales of the involucre biseriate, ovate, striate: rays 4 or 5, oblong; disk-flowers externally pubescent: chaff ovate, scarious, obscurely dentate at the apex: scales of the pappus linear-lanceolate, laciniate at the apex, shorter than the tetragonal hirsute achene. — Leopoldina, xxiii. 6. *Tetrachyron Orizabaensis*, Schz. Bip. *fide* Klatt, l. c. — Peak of Orizaba, altitude 8,000 to 10,000 feet, *Liebmann*, no. 390. Not seen by the writers. Description translated and condensed from the original characterization.

Subgenus 5. TEPHROCALEA, Gray. Heads few or solitary, rather large for the genus: scales of the pappus 4 to 5: leaves ovate, entire, abrupt at the base and slender-petioled, canescent-tomentose or -tomentulose beneath. — Proc. Am. Acad. xv. 38.

26. C. discolor, Gray, l. c. Leaves ovate-oblong, obtusish, mucronulate, glabrous above, very finely tomentulose beneath: heads about 5 at the summits of the branches, 9 lines in diameter including the spreading rays: pedicels long, an inch or more in length, very finely puberulent or nearly smooth. — Mexico without locality, *Th. Coulter*, no. 351. A very distinct species apparently never rediscovered.

27. C. tomentosa, Gray, l. c. Leaves ovate, subcordate, rounded at the apex, densely tomentose and canescent upon both surfaces when young but glabrate above: heads solitary, terminal: peduncles very tomentose, rather stout and somewhat thickened upward. — Between San Luis Potosi and Tampico, *Palmer*, no. 1108. Not since collected.

Species of uncertain affinities.

28. C. sessiliflora, Less. Shrub: leaves very obtuse or subcordate at the base: heads discoid, about 10-flowered: involucre cylindrical: chaff broad, obovate, muticous at the apex. — Linnæa, v. 158. — Mexico, *Humboldt*. A species as yet wholly obscure; the characters are drawn from Lessing's scanty description.

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V. — A PROVISIONAL KEY TO THE SPECIES OF POROPHYLLUM, RANGING NORTH OF THE ISTHMUS OF PANAMA.

* Leaves with broad obtuse ovate or elliptic-oblong usually thin lamina, rather abruptly contracted at the base to a slender petiole.

\+ Heads very long; involucral scales at maturity 8 to 12 lines in length: peduncles conspicuously clavate: erect scarcely distinct annuals.

1. P. macrocephalum, DC. Prodr. v. 648.
2. P. ruderale, Cass. Dict. Sci. Nat. xliii. 56.
3. P. ellipticum, Cass. l. c.

\+ \+ Heads shorter; involucral scales about half inch in length: peduncles scarcely or not at all thickened toward the summit.

\+\+ Leaves with pellucid glands on the surface as well as at the margins.

4. P. Ervendbergii, Gray, Proc. Am. Acad. xix. 35.
5. P. nummularium, DC. l. c. 649.

\+\+ \+\+ Glands of the leaves marginal or none.

= Leaves broad, thickish: petioles rather short: probably a single species.

6. P. viridiflorum, DC. l. c. 648.
7. P. Lindenii, Schz. Bip. in Seem. Bot. Herald, 308.

= = Leaves thin and delicate.

a. Heads nodding or almost pendulous.

8. P. nutans. Leafy shrub with slender terete fuscous branches (marked with small light colored lenticels) and almost filiform branchlets: leaves thin, elliptic, entire, or crenulate, obtuse but often mucronulate at the apex, obtuse or acutish at the base, 8 to 14 lines long, half as broad; marginal glands 4 to 6 on each side the leaf; petioles filiform, 3 or 4 lines long: heads numerous, about 9 lines long: peduncles clustered at the ends of the branches in 3's and 4's: involucral scales 5, oblong, obtuse, 6 lines long, somewhat carinate, green, with double row of linear glands: flowers white or nearly so, 9 lines in length; limb of the corolla sub-bilabiate, shallowly toothed: achenes 5 lines in length. — Collected by *C. G. Pringle*, in mountains near Lake Chapala, 16 December, 1889, no. 2976, and by the same collector on rocky hills, Querendaro, Michoacan, 25 October, 1892; later by *E. W. Nelson*, between Chilapa and Tixtla, Oaxaca, altitude 5,200 to 7,000 feet, no. 2170. Mr. Pringle's plants were at first determined as *P. Ervendbergii* and so distributed. On subsequent comparison with that species they appear thoroughly distinct, having only marginal glands on the leaves, nodding instead of erect peduncles, less deeply cleft corolla, and longer achenes.

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b. Heads erect: slender annual.

9. P. Pringlei, Robinson, Proc. Am. Acad. xxvii. 178.

c. Heads erect: shrubs.

10. P. Jorullense, Cass. "Leaves 1 inch long, eglandular: petioles 6 to 7 lines long: scales of the involucre green." Dict. Sci. Nat. xliii. 57. *Kleinia Jorullensis,* HBK. Nov. Gen. & Spec. iv. 156, t. 356, whence description.

11. P. Nelsonii. Branching shrub, 1 to 2 feet high: stems terete, striate, purple: leaves chiefly opposite, rather small and distant; blade elliptic or oblong, obtuse, 6 to 8 lines long, 2 to 3 lines broad, rather gradually narrowed to a slender petiole (2 or 3 lines in length); glands few on the margin or often only a single one at the end of the mid-nerve: heads subcorymbose at the ends of the branches, 7 lines long, about 30-flowered; scales of the involucre 5, linear-oblong, acute, purple especially toward the summit, flat, marked with 2 rows of linear glands: corollas dark purple, 3½ inches long: achenes strongly tapering, 3 to 3½ lines in length. — Collected by *E. W. Nelson*, in Oaxaca, between Panixtlahuaca and Jaquila, altitude 5,000 feet, 26 February, 1895, no. 2399; also between Nopala and Mixistepic, altitude 800 to 4,000 feet, March, 1895.

* * Leaves rather broadly lanceolate, acute at both ends, slender-petioled.

12. P. Palmeri, Rose, Contrib. U. S. Nat. Herb. i. 338, t. 34.

* * * Leaves narrowly elliptic- or linear-oblong, obtuse or obtusish, gradually narrowed to a sessile or short-petioled base.

13. P. Seemannii, Schz. Bip. l. c.

14. P. obtusifolium, DC. l. c. 650.

15. P. decumbens, DC. l. c.

* * * * Leaves lance-linear, sessile, and amplexicaul.

16. P. amplexicaule, Engelm. in Gray, Pl. Wright. i. 120.

* * * * * Annuals or more commonly perennials, often shrubby at the base: leaves very narrow; truly linear or subulate, or lance-linear and acute or acutish, sessile or subsessile, but not amplexicaul.

+ Mexican species: corolla shallowly and regularly 5-toothed; teeth deltoid: achenes 2½ to 3½ lines long: involucral scales green or glaucous, not dark purple.

17. P. scoparium, Gray. Leaves truly linear or terete, half a line in breadth: peduncles inch or more in length. — Pl. Wright. i. 119.

18. P. pausodynum. Shrub: stems geniculate, branched, covered with smooth reddish brown cortex: branchlets straight, erect, sulcate-angulate, glaucescent: leaves scattered, linear-lanceolate, narrowed to an obtusish apex, attenuate at the base to a short petiole, slightly succulent,

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3-nerved, slightly reticulated, 2 inches long, 2 to 2½ lines broad, entire; marginal glands elliptical, usually 2 or 3 on each side and often one at the end of each leaf: heads 6 to 8 lines long, 25–30-flowered, rather densely clustered in terminal flat-topped leafy cymose corymbs (2 or 3 inches in breadth); individual peduncles shorter than the heads: scales of the cylindrical involucre 5, oblong, obtuse or rounded at the apex, 5 lines long, 1 to 1½ lines broad, pale green, with a double line of dark linear glands near the middle: flowers white. — *P. Seemanni*, Wats. Proc. Am. Acad. xxiv. 57; Braudegee, Zoe, i. 313; not Schz. Bip. — Collected by *Dr. Edward Palmer* in crevices of exposed rocks in high mountains near Guaymas, Sonora, 1887, no. 279 (distributed as *P. Seemannii*, var.). According to Dr. Palmer's notes the plant is called *Maravilla* by the Mexicans and used for headache.

+ + Mexican species with corolla more deeply cleft and more or less distinctly bilabiate; teeth lanceolate; achenes 2½ to 3½ lines in length.

++ Achenes long and slender, tapering at the apex, about 4 lines long.

19. P. gracile, Benth. Leaves fleshy, subterete. — Bot. Sulph. 29.

20. P. n. sp.? aff. *P. gracile.* Leaves not fleshy, flat, very narrowly lance-linear, 1 to 2 inches long, a line or two broad, with regular marginal glands: heads solitary, terminal on very short slender peduncles: cylindrical involucre green, slender; scales with purple border and glands. — A tall slender, much branched leafy plant collected at Fronteras, Sonora, by *C. V. Hartman*, altitude 4,550 feet, 25 September, 1890, no. 8.

++ ++ Achenes shorter, 2 to 3 lines long: involucre very dark-purple, often pruinose-glaucous.

= Spreading annuals: very likely a single species.

21. P. coloratum, DC. Prodr. v. 650.

22. P. tagetoides, DC. l. c.

= = Perennials, a little shrubby at the base.

a. Involucral scales obovate, very broad and obtuse.

23. P. filifolium, Gray, Proc. Am. Acad. xviii. 107, xix. 35.

b. Involucral scales narrower, oblong.

24. P. Linaria, DC. l. c. 649.

+ + + Lower Californian shrubs, with geniculate and much branched stems, short subulate fleshy leaves, and short many-flowered heads: achenes only 1½ lines in length.

25. P. crassifolium, Wats. Proc. Am. Acad. xxiv. 57.

26. P. tridentatum, Benth. Bot. Sulph. 30.

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VI. — DESCRIPTIONS OF NEW OR LITTLE KNOWN PHANEROGAMS, CHIEFLY FROM OAXACA.

Discorea composita, Hemsl. Mr. E. W. Nelson has rediscovered this species at Santa Efigenia, Oaxaca, altitude 500 feet, 18 July, 1895, no. 2828, and also between Topana, Oaxaca, and Tonala, Chiapas, altitude 200 to 500 feet, 1 to 3 August, 1895, no. 2855. The specimens from Santa Efigenia represent the hitherto unknown staminate plant from which the following supplementary characters are derived: foliage and inflorescence of the ♂ plant as in ♀: segments of perianth 6, oblong, obtuse; the inner slightly larger: stamens 6, all perfect, free from each other and borne upon the base of the perianth-segments, the three opposite the outer segments a little shorter than the others: filaments not noticeably rigid nor flattened, considerably exceeding the very short anthers: the interior of the flower containing a conical rudimentary ovary.

Habenaria subauriculata. Glabrous, 5 to 10 inches high: tuberiform root single, ovoid, an inch long: stem flexuous, leafy: leaves ovate, acutish or acute, 3-ribbed, sheathing by the slightly narrowed base, 1 to 1½ inches long, a third or half as broad: spike 2 to 6 inches long, several – many-flowered: bracts ovate-lanceolate, acuminate, about equalling the ovary: flowers green: upper sepals 3-nerved, about 3 lines long, obtusish, the upper broadly ovate, galeate, obtusish, 3-nerved, 3 lines long; the lateral ones narrowly ovate, obtusish, slightly exceeding the upper one: lateral petals linear-oblong, obtusish, slightly falcate, subauriculate on the lower side at the base, otherwise entire, 2 to 2½ lines long; labellum deeply 3-parted, the divisions linear, the lateral divaricately spreading and slightly curved upwards, 2½ to 3 lines long, about equalling the middle lobe: spur slender, scarcely clavate, green, about 4 lines long. — Collected by C. G. Pringle, on grassy slopes, Las Sedas, Oaxaca, altitude 6,000 feet, August, 1894, no. 4830. Habit of *H. flexuosa*, Lindl., and *H. clypeata*, Lindl., but with lateral petals undivided.

Spiranthes Oaxacana. Glabrous (except flowers): root a fascicle of numerous thickened tuberiform fibres: stem erect, a foot to a foot and a half high bearing 1 or 2 foliar leaves at the base and loosely sheathed for the rest of its length by membranaceous striate-veiny ovate-acuminate bracts: leaves oblong, 3 inches or more in length, three fourths inch in breadth, sheathing at the narrowed base, scarcely persisting until the perfecting of the flowers: flowers in a dense ovate subcapitate spike, slightly exceeding the conspicuous ovate-acuminate

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silvery diaphanous brown-veined bracts: sepals finely pubescent on the outer surface; the lateral sepals linear-oblong, 6 lines in length, obtuse, 3-nerved, not fleshy; the dorsal one ovate-lanceolate, obtusish, about the same length: petals linear-oblong, obtusish, 3-nerved, about equalling the sepals; labellum long-unguiculate; lamina oblong, 5 lines in length (about equalling or slightly exceeding the claw), 3½ lines broad, with a median lance-shaped callous thickening just above the thickish claw; the latter involute on the margin and somewhat sulcate above. — Collected by C. G. Pringle, on hills above San Felipe, Oaxaca, altitude 6,000 feet, 31 December, 1894, no. 6101.

Cranichis thysanochila. Glabrous throughout, 6 to 8 inches high: roots several, elongated, thick, tuberiform, obtuse, covered with fine short rootlets: leaves basal, ovate, acute, thin, smooth, 1½ to 3 inches long, half to two thirds as broad, subsessile; the contracted base membranous, amplexicaul: stem slender, flexuous, bearing about 5 lanceolate attenuate sheathing green bracts: spike 2 to 4 inches in length, only moderately dense: floral bracts ovate-lanceolate, sharply acuminate, green, 3 lines in length, about equalling the ovary: flowers spreading, nearly half inch in length: floral envelopes white; sepals oblong, obtuse, 1-nerved, subequal, about 2 lines in length; lateral petals broadly spatulate or narrowly obovate, obtuse, 1-nerved, about equalling the sepals in length; lip superior, obovate, cuneate, short-clawed, biauriculate at the base, terminated at the apex by an emarginate and fimbriated appendage; the inner surface longitudinally somewhat 2-crested. — Collected by C. G. Pringle, on calcareous banks, Las Hoyas Cañon, Oaxaca, altitude 4,500 feet, 2 November, 1894, no. 6023. This species differs from others of the genus in the fringed apex of the lip.

Microstylis platyglossa. Erect, a foot high, glabrous, 1-leaved: bulb three fourths inch in diameter: sheath subsolitary, short, obtuse: leaf oval, amplexicaul at the subcordate base and rounded or very obtuse at the apex, 1¾ to 2½ inches long, 15 to 18 lines broad: peduncles about 2 inches long; racemes 6 to 8 inches long, bracts ovate, acute, a third to half as long as the slender pedicels, these nearly horizontal, 1½ lines long: flower purple (the labellum sometimes lighter colored), inverted by the torsion of the pedicels, bringing the labellum downward: sepals oblong, obtuse, 1-nerved, about a line long, the upper odd one erect, the lower pair reflexed: lateral petals linear, reflexed; labellum broadly deltoid, one third broader than long, obtuse, about a line in length, dark purple or yellow (both colors sometimes occurring on the same specimen). — Collected by C. G. Pringle, on the Sierra de San Felipe, Oaxaca,

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altitude about 10,000 feet, August, 1894, nos. 5614, 5614 a, and by E. W. Nelson, in the same locality, no. 1140.

Microstylis streptopetala. Slender, 6 to 18 inches high, 1-leaved: bulb oval, half inch in diameter; sheaths 2, closely surrounding the base of the stem, obtuse: leaf elliptic-oblong, cuneate at the amplexicaul base, acutish or obtuse at the apex, 1½ to 3 inches long, 4 to 8 lines broad: naked and angled peduncle about equalling the stem (2 to 4 inches in length): spicate inflorescence strict, slender, 2 to 8 inches long, 2 to 3 lines in thickness, very densely flowered above but looser below: bracts very short ovate-deltoid, obtusish: flowers sessile: sepals 3-nerved, green, oblong, obtuse, the upper somewhat falcately incurved, 1½ lines long, green; lower 2 lines long: lateral petals linear, spirally coiled or twisted, greenish white; labellum deltoid, strongly auriculate, minutely 3-toothed at the apex, half as long as the upper sepals, in dried state nearly black; margins somewhat thickened and slightly incurved; auricles oblong and obtuse.— Collected in flower by C. G. Pringle on dry pine ridges, Sierra de San Felipe, Oaxaca, at 9,000 to 10,000 feet altitude, 30 July, 1894, no. 4808. Most nearly related to *M. montana*, Roth, but with very different lip.

Phoradendron Forestieræ. Glabrous throughout: branches terete, olive-green; branchlets ancipital: leaves narrowly oblong, with rounded apex and cuneately narrowed base, sessile, 1-nerved, or very obscurely 3-nerved, yellowish green, inch to inch and a half long, 1½ to 2½ lines wide: inflorescences of ♀ plant axillary, solitary, opposite, moniliform, 5 to 9 lines in length, flowers in 1 to 4 globular 10–12-flowered clusters, becoming deeply imbedded in the substance of the nodular rhachis; the clusters 2½ lines in diameter, tawny in color; the intervening necks 1 to 1½ lines long, about half enveloped in a loose sheath; the margins of the sockets holding the flowers finely ciliolate: divisions of the perianth 3 (rarely 4), deltoid, the free portion not a third of a line in length.— Collected by C. G. Pringle on hills between Tehuacan and Esperanza, Puebla, altitude 6,000 feet, 23 December, 1895, no. 6290. A species parasitic on *Forestiera*, and apparently most nearly related to *P. brachystachyum*, Oliv., which, however, is tomentulose on the branchlets, has simple not moniliform inflorescences, and larger more distinctly veined leaves.

Euphorbia Luciismithii. Tall branching tomentulose glaucous shrub, 10 to 15 feet in height: branches subterete, striate: leaves verticillate, 2–5-nate, elliptical, obtuse at both ends or subacute at the base, glabrous or glabrate above, paler and soft grayish-tomentulose beneath,

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10 to 16 lines long, a third to half inch broad: petioles 4 to 6 lines long, tomentulose: cymes compound, terminal, flat-topped, leafy: floral leaves oblanceolate, cuneate, mucronulate, 1-nerved, white or rarely red, about 3 lines in length, a line in breadth: involucres campanulate, puberulent, nearly sessile; lobes 5, fimbriated; glands 5, oblong; appendages oblong or subrotund, undulate, white, three fourths line long: capsules 3-lobed, nearly 3 lines long, glabrous seeds ashy, oblong, somewhat 4-angled, faces rugulose and marked with fine irregular brown lines. — Collected by Lucius C. Smith, at Rancho de Calderon, altitude 5,500 feet, 13 August, 1894, no. 181; also at Jaycatlan, altitude 4,300 feet, 10 September and 4 November, 1894, no. 182; also by C. G. Pringle, in rocky gulches, Monte Alban, Oaxaca, altitude 5,800 feet, 14 September and 27 November, 1894, no. 4903, and by E. W. Nelson, six miles above Dominguillo, altitude 4,500 to 5,500 feet, 30 October, 1894, no. 1880. Most nearly related to *E. leucocephala*, Lotsy, from which it differs in pubescence and form of appendages.

Euphorbia Oaxacana. Stems subterete, 2 to 5 feet high, green, rather densely pubescent near the summit, soon glabrate: leaves alternate, ovate-elliptic, entire, thin, obtuse at each end, appressed-villous on both sides and ciliated, 10 to 16 lines long, half as broad; slender soft-pubescent petioles becoming half inch in length: inflorescence a long narrow compound somewhat secund naked panicle: its leafless branches alternate, 1 to 3 inches in length, again branched and rather densely flowered, tomentose; buds roseate, tomentose: involucres in subcapitate peduncled cymes, white-tomentose as well as the short (1 to 1½ lines) linear-spatulate branchlets; glands 5, equal, oblong, with white subrotund or oblong 2–3-crenulate appendages (about a line long); involucral lobes fimbriate, green: styles deeply 2-parted; capsule green, glabrous, 1⅓ lines in diameter: seeds oval, ashy, faveolate. — Collected by C. G. Pringle, on ledges, Monte Alban, Oaxaca, altitude 5,800 feet, 23 November, 1894, no. 6070.

Euphorbia subcærulea. Erect much branched annual, glabrous throughout, 2 feet in height: stem and slender branches terete, striate, livid: leaves elliptic-ovate, entire, thin, green above, a little paler and glaucescent beneath, rounded or very obtuse at the base, rounded or retuse at the apex, 3 to 8 lines long, nearly two thirds as broad: petioles filiform, nearly equalling the leaves: inflorescences open cymose-paniculate: floral leaves very small, elliptic-ovate to subrotund, subsessile, white or bluish: involucres (including appendages) 1½ lines in diameter; glands 5, oblong, sessile, with suborbicular entire appendages, these at

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first light blue, then changing to white, half line in diameter, spreading: stigmas deeply 2-parted; divisions clavellate: capsule smooth, about a line in diameter: seeds oblong, light blue, three fourths line in length, deeply pitted and with a conspicuous caruncle. — Collected by C. G. Pringle, on dry banks, Tomellin Cañon, Oaxaca, altitude 3,500 feet, 9 December, 1895, no. 6265.

Cardiospermum Galapageium. A slender climber with furrowed tomentulose stem and biternate leaves: leaflets oblong-lanceolate, attenuate, entire, abrupt at base, finely tomentose upon both surfaces, slightly paler beneath, prominently 1-nerved and pinnately veined, the lateral leaflets of each division much smaller than the terminal: peduncles slender, spreading, tendriliferous beneath the umbelliform inflorescence: sepals 4, the outer pair a line, the inner 2 lines long: glands upon the upper side of the disk short, rounded, not at all cornute. — *C. Corindum*, Rob. & Greenm. Am. Jour. Sci. ser. 3, L. 145, in part, not L. — Collected in the southern part of Albemarle Island, July, 1891, by Dr. G. Baur, no. 61. Distinguished by its narrow entire leaflets. *C. integerrimum*, Radlk., the only other species with similar foliage, known to the writers, has a 5-sepaled calyx and cornute glands.

Erythræa retusa. Erect glabrous annual, 6 or 8 inches in height: stem leafy, 4-angled, branched; branches erect or nearly so, mostly rather short and again branched: leaves oblong-elliptical, obtuse or mucronulate at the end, somewhat narrowed at the base, half inch long, 2 to 3 lines broad, the uppermost narrower and lanceolate: pedicels both terminal and lateral on the branches, short, 1 to 2 lines in length: flowers 4-merous, calyx-lobes lance-linear, attenuate, slightly carinate, 2 lines in length, green with narrow scarious diaphanous margins: corolla-lobes oblong, retuse, a line long, pale yellow in a dried state: fruit dark brown, 2½ lines long. — Collected by C. G. Pringle, in springy meadows, Sierra de San Felipe, Oaxaca, altitude 7,500 feet, 11 December, 1895, no. 6300. This species differs from *E. divaricata*, Schaffner, in its much shorter pedicels and erect not widely spreading branches; from *E. tetramera*, Schiede, in its retuse by no means acute corolla-lobes: from *E. stricta*, Schiede, in its 4-merous flowers. The flowers are small and appear to remain closed and to be cleistogamous.

Nama Pringlei. Low slender branching annual of similar habit to the following and with similar pubescence: leaves oblong, entire, rounded at the apex, rather gradually narrowed at the base to a short slender petiole: calyx as in the last: corolla showy, 5 lines long and equally broad, with short yellow tube and deep blue spreading rather deeply 5-lobed

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limb: styles a line long: capsule rugose, broadly ovate with depressed summit. — Collected by C. G. Pringle, on hills near Tehuacan, Puebla, altitude 5,500 feet, 24 December, 1895, no. 6286. A very attractive species, nearly related to *N. latifolium*, Gray, but with much longer calyx and larger corolla as well as different pubescence.

Nama Pueblense. Slender weak dichotomously branched annual, 3 to 6 inches high, spreading-pubescent: leaves ovate, obtuse, entire, thin, 10 to 12 lines long, half as broad, rather abruptly contracted to a slender petiole and covered on both surfaces with fine sub-appressed hairs with globular bases; and below with short golden yellow pedicelled glands: flowers short-pedicelled, grouped by 2's or 3's near the axils or extra-axillary and solitary somewhat above the fork of the terete purplish stem: calyx-lobes in fruit 4 lines in length, spatulate, densely hirsutulous with spreading white hairs: corolla small, pale blue (in dried specimen), tubular, with scarcely ampliated shortly 5-lobed limb, 2 to 2½ lines long: styles half line in length: capsule narrowly oblong, hispidulous near the apex, rugose, about 2 lines in length, obtusish: seeds brownish, rugose. — Collected by C. G. Pringle, on hills near Tehuacan, Puebla, altitude 5,500 feet, 24 December, 1895, no. 6287. Habitally near to *N. latifolium*, Gray, but differing in its much longer more hirsute calyx, narrower capsule, and having leaves evenly pubescent over the entire surface instead of chiefly on the veins.

Berendtia levigata. Shrub 2 to 3 feet high, glabrous but somewhat vernicose especially upon some of the younger parts: stems and branches covered with a gray bark; branchlets very leafy especially at the ends: leaves rather broadly lanceolate or oblanceolate, sharply few-toothed above the middle and acute, cuneate to an entire short-petioled base, glabrous or (under a lens) slightly pulverulent but green on both surfaces and sometimes a little lucid, of firm texture, 1¼ to 1½ inches long, half as broad: peduncles opposite in the upper axils, 1-flowered, bibracteolate at or below the middle, the bractioles bearing rudimentary buds in their axils: calyx strongly prismatic, as in *Mimulus*, 6 lines in length, with 5 short broad subequal acuminate-mucronate teeth: corolla showy, much exserted, 1½ inches in length; throat rather gradually ampliated, orange with crimson spots; limb patulous, of broad rounded lobes: stamens scarcely exserted: capsule 6 lines in length. — Collected by C. G. Pringle, on calcareous hills near Tehuacan, Puebla, altitude 5,500 feet, 24 December, 1895, no. 6294.

Castilleia aurea. Slender annual of § *Epichroma*, a foot high, with terete glabrous flexuous branched stems and delicate pectinate

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foliage: leaves inch to inch and a half long, with 6 to 9 filiform-linear segments and narrow rhachis: flowers 9 lines in length, in long rather dense puberulent racemes; lower bracts much like the leaves, the upper gradually reduced to small lanceolate or subulate scales; pedicels erect, slender, 2 to 4 lines long: calyx funnel-form, gradually and considerably ampliated, with broad orifice oblique, scarcely split ventrally and not at all dorsally, about half inch in length, golden yellow: corolla concolorous, about 9 lines in length, puberulent upon the considerably exserted galea: capsule ovate-oblong, acutish, 3 lines in length. — Collected by C. G. Pringle, on wet bluffs of barrancas above Cuernavaca, State of Morelos, altitude 7,000 feet, 19 November, 1895, no. 6204. Nearly related to *C. tenuifolia*, Mart. & Gal., and *C. gracilis*, Benth., but distinguished from the former by its yellow flowers, more dense and continuous inflorescence, narrower acuter capsule, and smaller seeds; from the latter by the color of the flowers and much more exserted galea, denser racemes, etc.

Carlowrightia glandulosa. Low much branched shrub, 1 to 3 feet in height, densely glandular-tomentose and viscid: cortex of the older branches pale gray: leaves ovate, acute, entire, cordate, soft-pubescent upon both surfaces, the larger ones 12 to 15 lines in length, three fourths as broad, the floral ovate-lanceolate to lanceolate, half inch in length, somewhat acute at the base: petioles nearly or quite half the length of the leaf: flowers 1 to 4 in the opposite axils, closely sessile: calyx-tube very short, divisions narrowly linear-attenuate, 3 lines in length, glandular-pubescent: corolla bluish, 4-parted; the emarginate posterior lobe purple-veined and marked with yellow at the centre; tube 2 lines long; lobes 4 to 5 lines in length: capsule glabrous and lucid, three fourths inch long, with pungent tip, seeds orbicular, dark brown with lighter colored margin, $2\frac{1}{2}$ lines in diameter. — Collected by C. G. Pringle at Monte Alban, near Oaxaca, altitude 5,500 feet, 5 December, 1895, no. 6276. This species is nearest *C. pubens*, Gray, but differs from it most obviously in its cordate and considerably larger lower leaves, as well as larger flowers and seeds.

Carlowrightia (?) Pringlei. Shrub, 3 to 5 feet high, with slender glabrous terete stems covered with smooth grayish brown cortex: leaves ovate-lanceolate, acute, entire, rounded at the base, glabrous on both surfaces or minutely strigillose on the veins beneath, 8 to 12 lines long, a third as broad; petioles a fourth inch long, glabrous but often with a tuft of white hairs at the base within: floriferous branches slender, recurved: flowers sessile, secund, solitary or 2 together in the same axil, the opposite axil being empty: bracts small, subulate: calyx-tube very short;

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segments 5, linear-attenuate, glandular-pubescent, 1½ lines long: corolla bluish white (in dried specimen): tube slender, 4 to 6 lines long, about equalling the 4 lobes: anther-cells equal and subcontiguous, muticous: capsule glabrous, half inch in length. — Collected by C. G. Pringle, dry slopes, Tomellin Cañon, Oaxaca, altitude 3,500 feet, 30 November, 1895, no. 6261. A plant which with about equal propriety might be referred to *Dianthera*.

Jacobinia candicans, Benth. & Hook. f. "Gen. ii. 1115" according to Hook. f. & Jacks. Ind. Kew. i. 1246. *Dianthera candicans*, Benth. & Hook. f. "Gen. ii. 1113" according to Hemsl. Biol. Cent.-Am. Bot. ii. 517. *Adhatoda candicans*, Nees in DC. Prodr. xi. 396. *Jacobinia Mexicana*, Hemsl. l. c. 521, as to plants of *Galeotti* and of *Liebmann*. Excellent and copious material of this doubtful plant has now come to hand from the following sources. Vicinity of Cuicatlan, Oaxaca, altitude 1,800 to 2,500 feet, E. W. Nelson, no. 1698, and in same locality V. González, no. 48; also in Tomellin Cañon, altitude 2,500 feet, C. G. Pringle, nos. 5638, 6260. The plant is a shrub 3 to 5 feet high with the whole habit and inflorescence as well as corolla of *Jacobinia*, to which it would seem best to refer it notwithstanding its slightly disjoined anther cells. Indeed the very close habital resemblance between this species and *Jacobinia Mexicana* has led to a confusion of the two for Mr. Hemsley in the places cited ascribes Galeotti's no. 911 both to *Dianthera candicans* and *Jacobinia Mexicana*. The plants of recent collection mentioned above correspond in all points to Liebmann's specimen from Tehuacan, and differ much in calyx and bracts from Seemann's plant of N. W. Mexico. In the latter plant (*J. Mexicana*, Seem.) the bracts are minute, much shorter than the 5-toothed calyx. In the former (*J. candicans*) the bracts about equal the calyx and this is much more deeply 5-cleft. The corolla of *J. candicans* is bright scarlet rather than purple as described by Nees.

Oldenlandia xestosperma. Erect glabrous perennial, several-stemmed from a slightly ligneous base: stems terete, moderately branched above, 1 to 2 feet high: leaves linear, 1-nerved, an inch to an inch and three fourths in length, less than a line in breadth: inflorescences terminal few-flowered cymes; bracts small, subulate; pedicels filiform, 1 to 3 lines in length: flowers strongly heterogone-dimorphous: calyx-lobes in anthesis but half line long, subulate, about equalling the tube: corolla purplish, nigrescent in drying, 4 lines in length, gradually widened from the base; limb of 4 triangular erect teeth: capsule obovate, 2 lines in length, entirely inferior, dehiscing to the base: seeds slightly angled,

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light colored, yellowish, highly polished and shining, half line or less in diameter. — Collected by C. G. Pringle in open glades, Sierra de San Felipe, Oaxaca, altitude 8,000 feet, June, 1894, no. 4692. Habit of *Houstonia purpurea*, var. *tenuifolia*.

Eupatorium eriocarpum. Stem tall, 5 to 8 feet in height; branches glabrate, angled, lucid, yellowish brown; branchlets puberulent but soon glabrate: leaves opposite, ovate or rhombic ovate, crenate-serrate, acuminate to an obtusish apex, cuneate or rather abruptly contracted at the mostly unequal-sided base, glabrous on both surfaces except on the veins and at their axils, 2 to 3 inches in length, a third to half as broad, neither coriaceous nor rugose, scarcely paler beneath, pinnately veined; petioles 2 to 3 lines long: thyrsoid inflorescences terminal on the upper branchlets and together forming large ovate leafy panicles; slender peduncles and short pedicels often nodding, covered with fine and somewhat sordid pubescence: heads mostly 5-flowered, 5 to 6 lines in length: scales of the involucre ovate to ovate-oblong, obtuse, finely striate, ciliolate, imbricated in 3 or 4 series: corolla-tube slender, $2\frac{1}{4}$ lines in length, larger at the base than at the summit, without any apparent throat; teeth very short: style branches dark colored, strongly clavate: achenes turbinate, so densely covered with white woolly or silky pubescence as to obscure their 5 angles, about 2 lines in length, narrowed at the base to a glabrous callous and somewhat pungent lip; pappus-bristles white, slightly exceeding the achene, about 50 in number. — Collected by C. G. Pringle, in Tomellin Cañon, Oaxaca, altitude 3,000 feet, 22 December, 1894, no. 6112.

Eupatorium rupicola. Shrub, 5 to 10 feet in height: branchlets reddish brown, terete, finely and densely fuscous-puberulent: leaves opposite, petiolate, ovate, acuminate, crenate-serrate, 3-nerved, rounded or obtusish at the base, green and sparingly puberulent or glabrate above, paler and grayish-tomentulose beneath, 14 to 18 lines long, 7 to 12 lines broad; petioles reddish, puberulent, 3 lines long: inflorescences 6–10-headed flat-topped umbelliform corymbs terminating short opposite lateral and terminal branchlets (1 to 2 inches in length), and together forming more or less elongated leafy panicles; pedicels densely pubescent, ascending, 2 to 4 lines long, subtended at the base by very reduced leaves and often bearing one or more short subulate bractlets: heads $3\frac{1}{2}$ to 4 lines in height; involucre relatively short, imbricated in about 2 series; scales 10 to 15, subequal, $1\frac{1}{2}$ lines in length, oblong, acutish, puberulent; flowers about 16, purplish white: corolla $2\frac{3}{4}$–3 lines, gradually enlarged upward: achenes linear, a little over a line in length, rather densely white-pubes-

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cent. — Collected by C. G. Pringle on dry ledges of the Sierra de San Felipe, Oaxaca, altitude 7,500 feet, 9 October, 1894, no. 4970.

Chrysopsis Brandegei. Low villous perennial, 3 to 5 inches high, with spreading branched scaly rootstock and numerous densely tufted stems: leaves spatulate, entire, gradually narrowed below into slender petioles, rounded at the summit but mucronate-acuminate at the very apex, 1-nerved, finely grayish-pubescent and covered with very short yellowish glandular or resinous-tipped hairs (so short as to appear when viewed from above merely as sessile globules), and spreading-villous on the edges, 7 or 8 lines long including the petioles; lowest leaves shorter, densely crowded at the base, and often canescent with more appressed pubescence: peduncles terminal, slender, erect, flexuous, terete, 1½ to 2 inches long, villous with spreading hairs and also closely covered with the minute glandular hairs, entirely leafless but sometimes bearing one or two short filiform bracts: heads solitary, discoid, 6 to 8 lines in diameter, half inch in height, 40–45-flowered: scales of the involucre very unequal, imbricated in about 4 series; the outer ones very small, a line in length, very villous, the inner oblong, purplish, rather abruptly but acutely pointed, flat and smoothish, ciliolate on the margin, 3½ lines long, half to two thirds line broad: corollas 5-toothed, golden yellow, glabrous, 4 lines long: pappus manifestly double, the outer bristles very unequal: stigmas sometimes 3: achenes (immature) densely silky-villous, about a line long. — *Chrysopsis* sp., Brandegee, Zoe, iv. 206. — Collected by T. S. Brandegee at San Pedro Martir, Northern Lower California, May, 1893.

Bigelowia pyramidata. Shrub, 2 to 3 feet high, much branched: branches white-woolly; branchlets striate: leaves fascicled, linear-acicular, entire, somewhat pungent, white-woolly beneath, strongly revolute at the margins, pale green and grooved above, 4 to 14 lines long, half line in breadth: inflorescences terminal pyramidal panicles: heads small, numerous, sessile or subsessile, spicately arranged along the spreading-ascending branches, subtended by fascicles of short spreading pungent leaves, discoid, few (5–7)-flowered: scales of the involucre linear-lanceolate, acute, scarious, diaphanous: flowers pale yellow, pappus scarcely tawny, of numerous fine unequal bristles: young achenes silky, the mature not seen. Collected by C. G. Pringle, on hills above Oaxaca, altitude 5,500 feet, 16 November, 1894, no. 6048. A species anomalous in its spicate-paniculate inflorescence but with the other characters of *Bigelowia*.

Lagascea tomentosa. Rather stout: stem subsimple, terete,

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tomentose, also somewhat glandular and villous, purplish: leaves ample, ovate, acuminate at the apex, acute at the petiolate base, dentate, tomentose on both surfaces, pale beneath, 3 to 5 inches long, nearly 1½ to 2 inches broad, scabrous on the margins: petioles 4 or 5 lines long, densely pubescent: inflorescences enveloped in ovate-lanceolate acuminate pubescent and ciliate bracts (6 to 8 lines long, 2 to 3 lines broad): involucres numerous, closely aggregated, villous, 3 lines in length, 1-flowered, unequally dentate, glandular in lines: corolla long, 6 lines in length, externally pubescent, the ampliate cylindrical throat exceeding the limb and the more slender proper tube: mature achenes not seen. — Collected by E. W. Nelson between Ayusina and Petatlan, Guerrero, altitude 5,000 to 7,000 feet, 14 December, 1894, no. 2121.

Trigonospermum tomentosum. Stout branching pubescent herb: stem terete, brownish or dark colored: leaves rhombic-ovate, 3-nerved from above the abruptly contracted then cuneately narrowed base, serrulate, acuminate, green and becoming scabrous above, paler and densely tomentose beneath, including the narrowed petiole-like base, 4 to 8 inches long, half as broad: inflorescence a much branched corymbose panicle, densely covered with short dark glandular-tipped hairs; bracts subulate: heads half inch in diameter: involucral scales about 2-seriate; the outer oblong, acutish, 3-nerved, ciliated: the inner broadly obovate, abruptly acuminate: ray-flowers 5; ligules broad, reversed-deltoid, deeply 3-lobed, bright orange-yellow, 3½ lines long; disk-flowers about 25, concolorous: chaff hyaline, obovate-cuneate to suborbicular, ciliated. — Collected by E. W. Nelson on the western slope of Mt. Zempoaltepec, Oaxaca, altitude 7,700 to 8,000 feet, 5 to 13 July, 1894, nos. 610, 617, and later between Panixtlahuaca and Jaquila, altitude 1,000 feet, 26 February, 1895.

Montanoa macrolepis. Stem, 3 to 5 feet in height, terete, fuscous, glabrous or somewhat pubescent: leaves opposite, sinuately 3-lobed; the lamina 3 to 5 inches long, 2 to 3 inches broad, very scabrous-pubescent above, somewhat paler and sparsely pubescent or glabrate beneath, 3-nerved above the base, and contracted below to a somewhat toothed wing, which does not quite reach the stem but terminates gradually or abruptly (usually with two rounded auricles), leaving a short naked petiole; lobes undulate-denticulate; the lateral short, broad, blunt or again subbilobed; the terminal ovate, obtuse, acutish or even acuminate: heads rather few and large, cymose-corymbed, individually pedunculate or grouped by 2's or 3's at the ends of the branches: involucral scales subbiseriate, oblong, obtuse or rounded at the apex, 3½ lines long: ray-

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flowers 10–12; ligules 6 lines long, 2 to 3 lines broad; disk-flowers numerous, with the tube about a third as long as the ampliated throat: fruiting heads globose, 1¼ inches in diameter; achenes 2 lines long: chaff lanceolate-attenuate, straight-pointed or nearly so, puberulent or almost glabrous except the strong ciliation of the margins, 4 to 5 lines long in anthesis, becoming 8 lines long in fruit. — Collected by C. G. Pringle, in gulches of hills of Las Sedas, Oaxaca, altitude 6,000 feet, 29 September, 1894, no. 4932, also by L. C. Smith, at Nacaltepec (Salomé), Oaxaca, altitude 6,500 feet, 21 September, 1895, no. 818.

Montanoa Rosei. Shrub 8 or 10 feet high: leaves opposite, slender-petioled, rhombic-ovate, serrate, not lobed, acuminate at the apex, cuneate at the base, rather harsh in texture, scabrous and somewhat rugose above, scarcely paler, finely pubescent and glandular-dotted beneath, 3 to 4 inches long, half as broad: corymbs ample: bracts linear: involucral scales lance-attenuate, sub-uniseriate, silky-villous, 2½ to 3 lines in length: disk-flowers about 4, with tube slender, nearly equalling the throat; rays about 3, about 2 lines in length: chaff densely fulvous-woolly. — *Montanoa* (*Enocoma*) sp., Rose, Contrib. U. S. Nat. Herb. i. 103. — Collected by Dr. E. Palmer, at Alamos, W. Mexico, 26 March to 8 April, 1890, no. 394.

Viguiera Nelsonii. Stem terete, densely silky-villous with white subappressed hairs: leaves attenuate at both ends, sessile, 3-nerved from above the base and pinnately veined, appressed silky-villous upon both surfaces, more densely so and paler beneath, 3 to 6 inches or more in length, ½ to 1¼ inches in breadth: heads 12 to 20 in number, 12 to 18 lines in diameter, borne in a terminal corymbose panicle; the individual peduncles an inch or two long: involucral bracts 2–3-seriate, narrowly oblong-lanceolate, silky-villous especially near the margins: somewhat thickened at the base; the tips lax and spreading: rays about 10, orange-yellow, oblong, slightly 2–3-toothed at the apex, 6 to 8 lines in length: disk-flowers more than 50, concolorous: chaff carinate, with strong midrib excurrent as a spreading tip: achenes somewhat compressed and inconspicuously 4-angled, appressed-villous: pappus of two aristæ somewhat broadened at the base, and intermediate squamellæ two on each side, ovate, ciliate-fringed. — Collected by E. W. Nelson, between Chilapa and Tixtla, Guerrero, altitude 5,200 to 7,000 feet, 17 December, 1894, no. 2169, and by L. C. Smith in mountains of Huitzo, Oaxaca, altitude 6,500 feet, 16 November, 1895, no. 899. As to character of achenes a dubious intermediate between *Viguiera* and *Encelia*, but in habit approaching more closely species of the former genus.

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Verbesina Nelsonii. Stout, apparently herbaceous: stem striate-angulate, puberulent under a lens, internodes entirely wingless or with a broadish irregular deciduous corky wing near the summit: leaves green and glabrous on both surfaces, oblong, acuminate, penninerved, crenate-serrate, 6 to 8 inches long, 1½ to 2 inches broad, below the middle slightly narrowed and somewhat crisped or undulate; the base broadly auriculate and amplexicaul, midrib prominent beneath, pale: heads numerous, of medium size, 4 to 5 lines in diameter, in a very dense terminal compound corymb; bracts oblong, small, scarcely herbaceous: pedicels tomentulose: involucre campanulate; scales about 10, subuniseriate, oblong, obtusish, 2 lines long; ray-flowers 4 to 6; ligules very small, yellow, 2 to 2½ lines long, nearly a line in breadth: chaff obovate, mucronate, pubescent on the outer surface especially on the prominent keel: achenes a line long, hispidulous, with conspicuous wing on each edge, awns subequal. — Collected by E. W. Nelson, between Ayusinapa and Petallan, altitude 5,000 to 7,000 feet, 14 December, 1894, no. 2118.

Verbesina Smithii. Branching shrub: branches glabrous, wingless, covered with a pale grayish cortex roughened with numerous lenticels: branchlets gray-tomentose: leaves alternate, lanceolate, attenuate at both ends but obtusish and mucronulate at the apex, rather shallowly serrate-dentate except at the cuneate short-petioled base, bright green and scabrous-puberulent above, white-tomentose beneath, 3 to 4 inches long, 10 to 14 lines broad: heads small, 2 lines high, 3 lines broad, not very numerous in small terminal corymbs; these 2 inches in diameter not exceeding the surrounding leaves: bracts small, grayish-tomentose as well as the pedicels: involucral scales about 3-seriate, elliptic-oblong, obtuse, green, pubescent on the outer surface, ciliated, a line long: disk-flowers 30 to 35; ray-flowers about 8; ligules yellow, 1½ to 2 lines long; chaff obovate, obtusish, yellow toward the summit, puberulent on the outer surface: achenes (immature) distinctly winged on each side; awns 2, slightly unequal. — Collected by L. C. Smith, at Jayacatlan, Oaxaca, altitude 4,500 feet, 10 September, 1894, no. 132.

Verbesina trilobata. Stems 5 to 10 feet in height, branched, glabrous, lucid, wingless, covered with light colored cortex: leaves opposite, decussate, rhombic in general outline, strongly 3-lobed, denticulate, gradually narrowed to a subsessile base, scabrous-puberulent above, grayish-tomentose beneath, subpalmately and rather obscurely 3–5-nerved from considerably above the base and reticulate-veined; terminal lobe elongated, ovate to oblong-lanceolate, acuminate; the lateral much shorter and rather blunt; sinuses rounded: corymbs much

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branched, terminal, leafy-bracted at the base; bracts oblong-lanceolate, acute; pedicels finely grayish-tomentulose; heads rather small, numerous, radiate, few-flowered; involucral scales about 3-seriate; the outer considerably shorter, linear-oblong, obtuse, 1 to 1½ lines long with subherbaceous tips; inner scales subscarious, about 3 lines long, a line broad, acute, glabrous, except the ciliolated margins: disk-flowers about 12; corollas glabrous; ray-flowers 2 to 3; ligules golden-yellow, 3½ to 4 lines long: mature achenes 2 lines long, conspicuously winged on each margin, hispidulous on the surfaces; awns subequal. — Collected by C. G. Pringle, in rocky gulches, Monte Alban, Oaxaca, altitude 5,600 feet, 15 August, 4 October, 1894, no. 4875.

Verbesina variabilis. Shrub: branches striate-angled, mostly wingless and nearly glabrous: branchlets hoary-puberulent or glabrous, usually bearing narrow irregular deciduous brown corky wings decurrent from the bases of the petioles: leaves alternate, short-petioled, ovate or lance-oblong, sharply and finely serrate or mucronulate-denticulate, acute to shortly acuminate at the apex, cuneately narrowed at the base, 2 to 3 inches long, 9 to 12 lines broad, above green, strigillose-puberulent and very scabrous to nearly smooth; below scarcely paler, soft-pubescent on the pinnate and reticulated veins or quite glabrous: heads of middle size in terminal subsimple or compound corymbs, pedicels grayish-tomentose to merely puberulent: involucral scales about 2-seriate, green, oblong, obtusish; ray-flowers 10 to 12, yellow; ligules 6 lines long, about 2 lines broad, finely 2–3-dentate at the apex; disk-flowers about 60, pubescent: chaff cuneate, the apex truncate with short recurved apiculus: achenes very narrowly winged on both margins, about 1½ lines long: awns 2, subequal. — Collected in three rather different forms, which, however, appear to have no satisfactory specific differences. The first, which may be regarded as the typical form, has rather broad dull green very pubescent leaves. It was collected by C. G. Pringle, Sierra de San Felipe, altitude 9,500 feet, 24 September, 1894, no. 4918, by E. W. Nelson, 18 miles southwest of the city of Oaxaca, altitude 7,500 to 9,500 feet, 10–20 September, 1894, no. 1393, and by C. Conzatti on Sierra de San Felipe, altitude 9,000 feet, 29 November, 1895, no. 31. A second form collected by Mr. Nelson on the top of the Sierra Madre near Chilpancingo, Guerrero, altitude 9,000 to 10,200 feet, 24 December, 1894, no. 2240, differs only in having narrower oblong leaves, which are somewhat lucid above and somewhat less pubescent. A third form, secured by Mr. Nelson at same place and date, no. 2215, has narrow oblong leaves, which are quite glabrous

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beneath, and slightly lucid but finely scabrous-puberulent above. The species, to judge from characters, must be near *V. Seemannii*, Schz. Bip.

Dahlia tenuis. Root a cluster of 6 or 8 stout fibres, each enlarged and tuberiform in the middle: stem single, erect, very slender, 1 to 2½ feet high, simple below, covered with a short and dense pubescence, almost tomentulose: leaves small for the genus, pinnate to bipinnate, somewhat deltoid in general outline, on slender divaricately spreading petioles of nearly their own length; leaflets lanceolate, acute or acuminate at both ends, finely and sharply serrate or irregularly 2–3-lobed, green and nearly or quite glabrous above, pale and finely pubescent beneath, 8 to 12 lines in length, 3 to 4 lines in breadth: heads few and subcorymbose, or even solitary, including the rays 1½ to 2 inches in diameter: outer involucre of about 6 narrow thickish obtuse bracts, reflexed during anthesis; the inner scarious bracts lance-oblong, about 6 lines in length: rays about 8, pistiliferous. — Collected by E. W. Nelson, 18 miles southwest of city of Oaxaca, altitude 7,500–9,500 feet, 10 to 20 September, 1894, no. 1364; also by C. G. Pringle, Sierra de Clavellinas, altitude 9,000 feet, 27 October, 1894, no. 5807; and by L. C. Smith, on mountains of Telixtlahuaca, altitude 7,500 feet, 27 July, 1895, no. 481.

Flaveria vaginata. Perennial with stout lignescent root: stems several, ascending from a decumbent or even prostrate somewhat branched base, terete, striated, purplish, with bilineate short grayish woolly pubescence, leafy above, naked below except for the persistent and sheathing bases of the fallen leaves: internodes very short: leaves linear-subulate, clasping at the base, very gradually attenuate, often fascicled in the axils 1(–3)-nerved, rather pale green, finely ciliated toward the base: heads small, closely aggregated into terminal solitary or corymbose-paniculate glomerules; these simulating the normal involucrate heads of the order: glomerules 6 to 8 lines in breadth, subtended by a few short recurved foliaceous bracts, and containing 30 or more heads: involucral scales 3 to 4 in each head, hyaline: ray-flower solitary, conspicuous, 2½ lines long, with oblong slightly 2–3-toothed yellow ligule: disk-flowers 5 to 7, yellow: achenes black, lucid, about 10-nerved. — Collected by E. W. Nelson between Coixtlahuaca and Tamazulapam, Oaxaca, altitude 7,000 to 7,700 feet, 12 November, 1894, no. 1933.

FLORESTINA PEDATA, Cass. With this species, *Schkuhria glomerata*, Rob. & Seaton, based on Mr. Pringle's nos. 4289 and 5006, and published in Proc. Am. Acad. xxviii. 109, is identical.

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Florestina platyphylla. Mr. Pringle's no. 4975, collected on Monte Alban, Oaxaca, and described in the Am. Jour. Sci. ser. 3, L. 156, as *Schukhria platyphylla*, appears upon further examination to be better placed in *Florestina*.

Dysodia serratifolia, DC. A specimen collected by L. C. Smith, below Jayacatlan, at 3,500 feet altitude, 9 February, 1895, corresponds with Ghiesbreght's no. 519, and with a fragment of the type from the De Candollean Herbarium, in all respects, except in having the leaves mostly alternate, not opposite as hitherto described. The uppermost only are subopposite.

Liabum glabrum, Hemsl. (Biol. Cent.-Am. Bot. ii. 232). This showy species, originally collected by Bourgeau, no. 1401, at Cuernavaca, in 1865, has now been rediscovered by Mr. Pringle in the same locality. His excellent specimens show the flowers to be bright orange-yellow and the leaves normally attenuate. Mr. Pringle notes that the plant attains a height of 15 feet.

Liabum Pringlei. Half shrub, 3 or 4 feet high: stems terete, fuscous-tomentulose: leaves opposite, ovate, acute, mucronulate-denticulate, green and puberulent above, densely white-tomentose and reticulated with brownish veins below, rounded and 3-nerved at the base, 3 inches long, two thirds as broad; margins revolute; naked petioles but 2 lines long: heads few, large, $1\frac{1}{4}$ inches in diameter, discoid: involucre campanulate, multiseriate; scales pale brown (in dried state), lanceolate, attenuate, slightly sericeous: flowers about 75 in a head, yellow, 10 lines in length: achenes $2\frac{1}{2}$ lines long, sericeous: pappus of elongated stramineous bristles and very short outer scales. — Collected by C. G. Pringle, on mountains near Lake Chapala, Jalisco, altitude 7,000 feet, 18 October, 1895, no. 6215.

Cacalia peltata, HBK., var. Conzattii. Stem 1 to 3 feet high: inflorescence lax, 1–20-headed; heads 25–40-flowered; involucre 12-phyllous; calyculate, scales covered with a densely spreading pubescence. — Collected by Professor C. Conzatti on the Sierra de San Felipe, Oaxaca, altitude 9,000 feet, 29 November, 1895, no. 27; also by C. G. Pringle in the same region, altitude 10,000 feet, 13 December, 1895, no. 6238.

Senecio prionopterus. Erect herb, 1 to 3 feet in height: stems somewhat flexuous, green, striate, slightly flocculose, rather broadly and interruptedly winged by the decurrent bases of the leaves, simple to the corymbose-paniculate flat-topped inflorescence: leaves lance-oblong, attenuate to a very sharp narrow apex, irregularly serrate-dentate, half inch

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broad, 3 or 4 inches long, glabrate above, floccose-tomentulose beneath, not narrowed at the base but decurrent upon the stem for nearly two inches in two broad wings, these sharply toothed especially near the lower end: bracts lance-linear: pedicels spreading, 4 to 15 lines in length, bearing several subulate bractlets: heads about 50, erect, half inch long and including the 8 or 10 spreading oblong golden-yellow rays, about 9 lines in diameter: involucre calyculate, about 20-phyllous; scales attenuate; disk-flowers 40 to 45, shortly 5-dentate: ligules 3 to 3½ lines long, 1 to 1½ lines broad, 4-nerved. — Collected by C. G. Pringle, on hills, at Las Sedas, Oaxaca, altitude 6,000 feet, 3 December, 1895, no. 6282.

Gochnatia Smithii. Shrub? leaves clustered near the ends of the branches, oblong, entire, obtuse, cuneate at the base, thickish, grayish and covered with a very fine short tomentum above (perhaps later glabrescent), much paler, tomentose and veiny beneath: heads in numerous slender close terminal globose glomerules, 8 lines long, about 6-flowered; involucres green, very slender, and gradually turbinate; the scales in many (8 to 10) series, extending as it were down upon the pedicels, ovate to lanceolate, obtuse, pubescent: style-branches short, flattened, rounded: divisions of the corolla subequal, narrow: achene subvillous, 1½ to 2 lines in length. — Collected by L. C. Smith, on hills of Cuicatlan, 30 April, 1895, at 3,000 feet altitude; also by E. W. Nelson along road from Totolapa to San Carlos, altitude 3,000 to 3,800 feet, April, 1895, no. 2546. Noteworthy for its very long slender closely imbricated involucres and globose inflorescences, the latter about 2 inches in diameter.

Perezia Cuernavacana. *Glabrous*: stems clustered, 2 to 3 feet high, striate-angulate, purplish, leafy: leaves oblong, obtuse and mucronulate at the apex, scarcely narrowed to the rounded subsessile base, sharply denticulate with pungent teeth, reticulated and lucidulous on both surfaces, 2 to 2½ inches long, 9 lines broad, ascending, imbricated, the uppermost gradually reduced: heads few, very large, about 30-flowered, 12 to 15 lines long and broad, terminal on long many-bracted peduncles: involucre turbinate, multiseriate; the scales greenish, silky-ciliate, the inner ones oblong, obtusish, 1½ to 2 lines broad near the summit, the outer gradually smaller and extending as subulate spreading bracts some distance down the peduncle: corollas lilac in dried state, 9 lines in length: pappus tawny; achenes puberulent, 3½ lines long. — A handsome species collected by C. G. Pringle, at Cuernavaca, altitude 7,000 feet, no. 6196.

Perezia umbratilis. Habit of *P. nudicaulis*: root horizontal, sending off numerous stout fibres; caudex multicipital, tufted with sordid

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white wool: leaves all radical, runcinately pinnatifid, glabrous or nearly so, petioled, thin, acutish; lobes 5 to 7, mucronulate-dentate: stems about a foot high, slender, dark colored, quite smooth, bearing a few scattered minute appressed subulate bracts and at the summit 2 or 3 heads on slender ascending branches: heads 9 lines long, about 18-flowered: scales of the involucre in 5 series, obtuse, flattish (not thickened nor firm in texture), dark colored, ciliated, otherwise glabrous, the inner ones 5 lines long: flowers lilac in dried state, 7 to 8 lines long (including the achenes). — Collected by C. G. Pringle, in shade, at Tomellin Cañon, Oaxaca, altitude 3,000 feet, 1 December, 1895, no. 5966. Closely related to *P. nudicaulis*, Gray, but having a more numerously seriate involucre with thinner flatter scales, and flowers nearly twice as large.

SONCHUS ASPER, Vill. Although so generally distributed as a weed upon waste heaps, etc., this plant does not appear to have been noted in Mexican lists. It has been collected at San Diego, Chihuahua, by Hartman, and near the city of Oaxaca, by Nelson, no. 1353.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

A REVISION OF THE ATOMIC WEIGHT OF MAGNESIUM.

By Theodore William Richards and Harry George Parker.

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Presented May 13, 1896.

Although numerous determinations of the atomic weight of magnesium have been made, the results obtained show such very wide variations among themselves that the value in use at present cannot be accepted with any certainty. It will not be necessary to review in detail all the work published, as most of it was done more than forty years ago, before quantitative methods had attained their present exactness; but the following table of methods used and results obtained will assist in a clear comprehension of the situation.

Previous work on the Atomic Weight of Magnesium.*

Synthesis of sulphate by the action of sulphuric acid on the oxide.	
Berzelius, 1826. Lehrbuch, 5th edition, III. 1227	25.3
Svanberg and Nordenfeldt, 1848. Erdmann's Journ. Prak. Chem., 1848, XLV. 473	24.7
Bahr, 1852. Erdmann's Journ. Prak. Chem., 1852, LVI. 310	24.8
Marignac, 1884. Annal. Chim. Phys., 1884, (5.), I. 289, 321	24.37
Conversion of sulphate into oxide.	
Jacquelain, 1851. Annal. Chim. Phys., (3.), XXXII. 195	24.5
Determination of sulphuric acid in sulphate.	
Gay-Lussac, 1820. Annal. Chim. Phys., XIII. 308	24.6

* We are indebted to F. W. Clarke for most of the above references.

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Scheerer, 1846. Poggend. Ann., 1846, LXIX. 535	24.5
Scheerer, 1847, Later Correction. Poggend. Ann., 1847, LXX. 407	24.5?
Jacquelain, 1851. Annal. Chim. Phys., 1851, (3.), XXXII. 195	24.2
Conversion of oxalate into oxide.	
Svanberg and Nordenfeldt. 1848. Erdmann's Journ. Prak. Chem., 1848, XLV. 473	24.7
Determination of chlorine in magnesic chloride.	
Dumas, 1859. Ann. Chim. Phys., 1859, (3), LV. 129, 187	24.6
Conversion of carbonate into the oxide.	
Marchand and Scheerer, 1850. Erdmann's Journ. Prak. Chem., 1850, L. 385	24.0
Scheerer, 1859, Later Correction. Liebig's Ann., 1859, CX. 236	24.0
Conversion of metal into oxide.	
Burton and Vorce, 1890. Am. Chem. Journ., 1890, XII. 219	24.29

It will be seen that, with the exception of the results obtained by the precipitation of the sulphuric acid with barium chloride and the precipitation of the chlorine with argentic nitrate, all the methods employed involve the use of magnesic oxide. The fact that all such results are untrustworthy was shown by T. W. Richards and E. F. Rogers* in their work upon the occlusion of gases by the oxides of certain metals when obtained by the ignition of various salts. The error from this source is so large that it seems hopeless to apply a correction to previous work upon the atomic weight of magnesium, as the amount of gas occluded depends in a large degree upon the method and thoroughness of ignition.

Concerning the results obtained by the precipitation of the sulphuric acid in magnesic sulphate, it is only necessary to point out the error due to the occlusion of various soluble substances present in the solution from which the precipitation was made. This error was recognized by Scheerer, after publishing his results, and an approximate correction was made; but such a correction does not merit much confidence, as will be seen.

In the work of Dumas it is evident that some magnesic oxychloride

* These Proceedings, Vol. XXVIII. p. 200.

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was formed, and he does not appear at all confident of the accuracy of his results. From the experience of the writers it does not seem likely that the method which he used would give magnesic chloride free from the oxide.

Preliminary Experiments.

Because considerable experience had been gained in a previous research,* upon the occlusion by baric sulphate of salts present in a solution from which this insoluble salt was precipitated, it was thought that Gay-Lussac's and Scheerer's method of precipitating magnesic sulphate with baric chloride might now be used with advantage, applying subsequently the necessary corrections for occluded substances. It had previously been found that the concentration of the solution and the method of pouring had a great deal to do with the amount of occlusion; and hence it seemed likely that, by working in a very dilute solution and pouring the magnesic sulphate into the baric chloride with extreme slowness, the occlusion of baric chloride might be large, but that the precipitate might be free from magnesium. Several experiments were made to ascertain the correctness of this supposition, but in each case it was found that, notwithstanding the precautions adopted, a very notable quantity of magnesium was occluded in the baric sulphate. It had been the custom in working upon this precipitation to fuse the weighed baric sulphate with sodic carbonate, to extract the sodic chloride thus formed, and to determine the chlorine with argentic nitrate and calculate as baric chloride, subtracting this amount from the total weight of baric sulphate found. This method gave very satisfactory results, but of course it could not be applied when the baric sulphate was mixed with magnesic chloride and sulphate as well as baric chloride, for then no one could discover the proportion in which each salt was present, with sufficient accuracy for work upon atomic weights.

The possibility of obtaining satisfactory results by the determination of the chlorine in magnesic chloride was now considered. The great disadvantage of this method, as is well known, is the extreme difficulty of obtaining pure anhydrous magnesic chloride. The usual method of igniting the double chloride of ammonium and magnesium was tried a number of times, but it was found that a quantity of the oxychloride was always formed. As indicators do not give a sharp reaction in the presence of magnesic salts, the hydrochloric acid driven off cannot be added

* These Proceedings, Vol. XXXI. p. 67.

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afterwards by titrating back to the neutral point with a weak acid solution, and it is therefore necessary to obtain in the first place magnesic chloride containing its full complement of acid.

The method was then modified by conducting the ignition of the double salt in a tightly covered platinum crucible in a stream of hydrochloric acid, instead of air. That a considerable quantity of oxychloride was usually formed, even under these conditions, was easily ascertained by dissolving the resulting product in water, when the oxychloride remained as an insoluble residue. In two or three cases, however, the amount of oxychloride formed was comparatively small; hence it was hoped that, if the right conditions could be found, the chloride might be obtained in a pure state. Another series of experiments with a modified apparatus was therefore undertaken. The expulsion of the ammonic chloride was conducted in a combustion tube and the number of drying tubes was increased, so that the hydrochloric acid gas might be as free as possible from water. The heat was applied very gradually, in order that the double chloride might be almost anhydrous before the sublimation of the ammonic chloride began. This method gave better results. It was observed that in two or three experiments, where the conditions had been unusually favorable, the resulting chloride gave a clear solution; and it seemed therefore probable that, if an apparatus could be devised to deliver a rapid stream of hydrochloric acid gas entirely free from aqueous vapor, the method might be successful.

Assuming that these conditions might be fulfilled, another difficulty remained to be overcome; for even if the magnesic chloride could be obtained in the combustion tube free from water and oxychloride, the problem still remained to weigh the salt without foreign admixture. If the boat were allowed to remain in the tube until cool, and then removed to a weighing bottle, the salt must absorb a very notable quantity of moisture from the air in the operation, however quickly this operation might be performed. The boat cannot be transferred to another tube and reheated, as the moisture present reacts upon the chloride, forming some oxychloride and liberating hydrochloric acid. If it is taken from the combustion tube while hot and allowed to cool in a weighing bottle, the same effect is produced. Dumas had met with the same difficulties in his work with this method, and he endeavored to compromise matters by removing the boat from the combustion tube when it had only partly cooled. As his subsequent results proved, however, the moisture from the air reacted upon the chloride, forming some oxychloride, which interfered seriously with the accuracy of his work. To obviate this

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difficulty the form of apparatus used by one of us* in drying strontic bromide was altered so that the boat could be transferred directly from the ignition tube to the weighing bottle without an instant's exposure to the outside air. In order to accomplish this result the hard glass tube was ground with a long tapering joint directly into the wider desiccating or cooling tube used to contain the weighing bottle. This desiccating tube had a sort of bulb or "pocket" blown upon one side of it, to receive the stopper of the weighing bottle, thus allowing the boat to be pushed past the stopper directly from the ignition tube into the bottle. Afterwards the stopper could be rolled into place with a rod provided for the purpose. The arrangement was used with great success in a recent determination of the atomic weight of zinc,† to which it was equally applicable. A reference to the annexed sketch will make the apparatus more comprehensible.

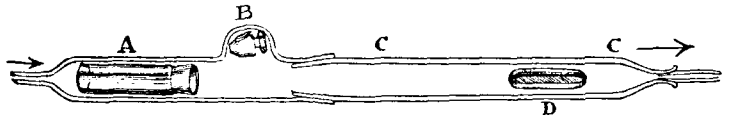

FIG. 1. — BOTTLING APPARATUS, HORIZONTAL SECTION.

A = weighing bottle. B = stopper of bottle. C C = hard glass tube.
D = Platinum boat containing fused magnesic chloride.

The desiccating apparatus for the hydrochloric acid gas consisted of two towers, composed of a number of glass bulbs filled with beads, upon which strong sulphuric acid was allowed to trickle from small reservoirs at the top into suitable receptacles at the bottom. This apparatus was constructed wholly of glass, with glass gridirons for flexibility, and ground or sealed glass connections. Joints were made tight with syrupy phosphoric acid (Morley). The hydrochloric acid, after being evolved by allowing strong sulphuric acid to run into a flask containing a strong solution of hydrochloric acid, was passed through a wash bottle containing sulphuric acid, thence through the towers just described, afterwards through a tube containing phosphoric pentoxide, and finally into the combustion tube. The apparatus was so arranged that the current of air from an aspirator could be passed through another set of towers, a duplicate of those used for drying the acid gas. By means of stopcocks either dry

* Richards, These Proceedings, XXX. 383.
† Richards and Rogers, These Proceedings, XXXI. 158, 174.

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hydrochloric acid gas or dry air could be passed through the tube containing the weighing tube and boat.

With the help of this contrivance it was found possible to drive off the ammonic chloride in a current of dry hydrochloric acid, to drive off the excess of acid from the fused magnesic chloride by means of a current of perfectly dry air, and to shut up the pure salt in a weighing bottle without the least possible means of access of a trace of aqueous vapor. The details of the method will be described later; magnesic chloride prepared after this fashion gives a perfectly clear solution in water. Since this problem was solved, attention was now turned to the preparation of materials for the atomic weight determinations.

Preparation of Materials.

The sample of ammonic magnesic chloride which will be hereafter referred to as sample No. 1, was prepared as follows. About five hundred grams of ordinary "C. P." magnesic chloride was saturated with hydrogen sulphide, a small amount of ammonia was added, and the whole was allowed to stand in a warm place for several days. To the supernatant liquid after decantation a small quantity of very pure ammonic oxalate was added. The magnesic chloride thus almost wholly freed from calcium was again decanted; and after more ammonic oxalate had been added, the whole was allowed to stand, and the clear liquid was yet once more decanted. The solution was then evaporated to dryness, and the resulting cake dried in an oven and ignited in a platinum dish. The mixture of magnesic oxide and oxychloride thus formed was washed with the aid of a filter pump for about sixty hours. At the end of this time, although the wash water contained no sodium, the insoluble precipitate was not free from that metal. The precipitate was therefore dissolved in hydrochloric acid, previously distilled in platinum for the purpose, and the solution was filtered. In order to eliminate the sodium, a portion of the magnesium was precipitated by passing into the solution a current of ammonia gas. The precipitate formed by this very wasteful process was washed for several days, at the end of which time it was found to be free from any appreciable traces of sodium and potassium, when tested with the spectroscope.

Ammonic chloride was now prepared by mixing streams of ammonia and hydrochloric acid gas. This gave ammonic chloride mixed probably to a certain extent with various amines, but free from inorganic salts. As the amines must be driven off later, it was not thought worth while to take the trouble of removing them at this stage of the work.

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The solution of ammonic chloride thus prepared was added to the solution of magnesic chloride obtained by dissolving the oxychloride in hydrochloric acid in proportions corresponding to formula $Mg.Cl_2(NH_4)Cl$, and the mixture was carefully evaporated to dryness and gently heated in an oven. It is of course unnecessary to say that all the latter part of this purification was done as far as possible in platinum. The solid cake was powdered in an agate mortar, and placed in a glass stoppered bottle which was kept in a closed jar. The double chloride thus prepared was then tested with the spectroscope, but no impurities could be discovered; and its solution in water was perfectly clear. Tests were made with ammonic oxalate and baric chloride, but in neither case was a precipitate formed on long standing.

The second sample of magnesic chloride was treated in a similar way up to the point where it was necessary to get rid of sodium and potassium. The solution was evaporated to dryness in a platinum dish with the aid of an alcohol lamp, and the resulting cake was gently ignited and then washed for a long time, nothing but platinum being allowed to come in contact with the material from this time forth, and all the heating being done by means of alcohol lamps to avoid the danger of contamination of sulphur from illuminating gas. The oxychloride thus formed was then dissolved in pure hydrochloric acid and filtered. By evaporating down again the magnesium was again rendered insoluble. This process was repeated again and again, until there was no trace of sodium or potassium remaining.

The ammonic chloride necessary for the preparation of the double salt from this second sample of magnesic chloride was prepared by digesting ammonic chloride with nitric acid to destroy the amines.* It was then dried, sublimed several times, recrystallized five or six times from its aqueous solution, and again sublimed in a current of air which had been passed through wash bottles containing respectively a concentrated solution of potash and sulphuric acid. After having been sublimed in this manner about ten or twelve times, it was dissolved in redistilled water and added to the sample of magnesic chloride. The whole was then filtered, evaporated to dryness, partly dehydrated, broken up and placed in a glass stoppered bottle. The usual tests were made as to its purity, but no traces of foreign matter were discovered.

The third sample of magnesic chloride, which was used for the final experiment in the last series, was at first treated in about the same way

* Krüss, Liebig's Annal., CCXXXVIII. 51.

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as the others. The precautions taken were somewhat greater, and the fractional precipitation with ammonic oxalate was continued long after the last traces of calcium discoverable by the spectroscope had disappeared from the precipitates of magnesic oxalate. The ammonic magnesic chloride, already very pure, prepared from this sample, was then crystallized eight or ten times, the last six or eight recrystallizations being conducted in platinum. From over a kilogram of magnesic chloride used in the beginning, the portion finally separated out consisted only of a few grams. This sample showed no traces of the sodium line when tested with the spectroscope; indeed, several other samples, obtained from the mother liquors of the purest sample, gave equally satisfactory negative spectroscopic results. Since the magnesic chloride had contained in the first place a very noticeable amount of sodic chloride, the fact of the complete elimination of the impurity seemed a satisfactory indication of the elimination of other foreign materials. The double chloride was dried over an alcohol lamp, and treated in the same manner as the other samples.

Purification of Silver.

No very great labor was expended upon the purification of the first quantity of silver, as the chlorine in magnesic chloride was to be precipitated with an undetermined excess of silver nitrate. Residues were therefore worked up by dissolving silver (obtained by reduction with zinc) in nitric acid, precipitating the metal as chloride, and converting the chloride into metallic silver by means of invert sugar. The reduced silver, after having been fused into buttons, was thoroughly washed and dissolved in nitric acid. The solution of argentic nitrate thus obtained was diluted very much with water, allowed to stand, and filtered just previous to using.

With the second sample, on the other hand, much greater care was taken, as it was designed in this case to ascertain the direct ratio between silver and magnesic chloride. The material came partly from some refined silver, purchased in the market, and partly from some pure silver residues remaining from previous work. The silver was precipitated from a solution of the nitrate with pure hydrochloric acid, and reduced by means of invert sugar and pure sodic hydrate, the sodic hydrate having been previously freed from heavy metals by electrolysis. Both the chloride and reduced silver were very thoroughly washed, the silver was dissolved in pure nitric acid, and the process was repeated. After this cycle of operations had been performed four or five times, the re-

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duced silver was fused on a cupel of sugar charcoal before the blowpipe. The resulting button was scrubbed with sand, and made the anode of a weak galvanic circuit in a solution of argentic nitrate prepared from the same silver. The cathode was a piece of pure silver wire, upon which the whole of the silver was deposited in a crystalline mass. The silver crystals were then removed from the solution and fused in a vacuum upon a boat of pure lime,* which was contained in a porcelain tube. Such a boat may be made by lining a porcelain boat with a mixture of three parts of pure lime and one part of pure anhydrous calcic nitrate, and igniting the mixture. The porcelain boat is thus covered with a firm, coherent layer of pure calcic oxide. In order to prevent the possibility of a trace of organic matter distilling off from the rubber stoppers usually used to close such a tube, a set of hollow brass stoppers were made, through which a current of cold water circulated. This latter device is due to a suggestion of Professor Hempel. The construction of this piece of apparatus is evident from the diagram.

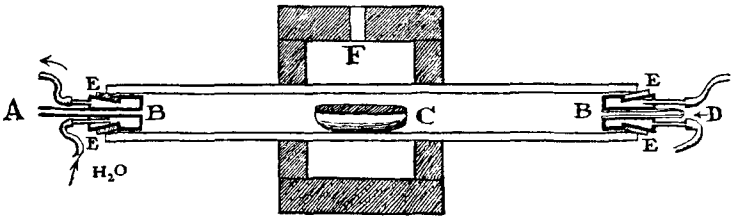

FIG. 2. APPARATUS FOR FUSING SILVER, VERTICAL SECTION.

A is connected with Sprengel pump. B B = hollow brass stoppers in porcelain tube. C = boat of lime containing silver. D = "window" for observation. E E E E = rubber packing of stopper. F = Fletcher furnace.

Of course the button after fusion showed no trace of spirting from contained oxygen. It was scrubbed with distilled water and clean sand, and divided into small pieces by means of a clean steel chisel. The fragments were alternately boiled in strong hydrochloric acid and digested in ammonia water, this process being repeated ten or fifteen times. The silver was finally washed with distilled water and afterwards kept in a desiccator, which was opened only when necessary to weigh out silver for a determination.

A portion of the second sample was treated in the same way, except that in the end it was fused on sugar charcoal before the blowpipe and

* These Proceedings, XXX. 379; XXXI. 173.

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cooled in the reducing flame. Particular pains were taken to prevent the absorption of oxygen, and the button did not show the slightest trace of having contained this gas. From this portion wire was prepared of various thicknesses, by means of a draw plate; and the weights of given lengths of these wires were determined, so that small weights could be made with considerable accuracy. Of course the wire was treated in the same fashion as the rest of the silver, in order to remove any iron which might be present on the surface.

The third and fourth samples of silver were prepared in the same manner as the second, the starting point being the pure residues left from the analyses made with previous samples. No qualitative nor quantitative difference could be observed between any of these preparations of silver. Fused upon sugar charcoal, they melted to a clear globule free from any film, — a fact which in itself, according to Stas, is an excellent test of the purity of silver, — and all gave practically the same results in later determinations.

All water used was redistilled with potassic permanganate, some of it being condensed in a platinum condenser and some of it by means of a tube of pure block tin, which was carefully tested in order to prove the absence of an impurity of lead. Considerable quantities upon evaporation in platinum left a scarcely appreciable residue, there being apparently no difference between the water condensed in tin and that in platinum.* The water was prepared as short a time as possible before being used, and was carefully kept in a suitable bottle fitted with a siphon, air being admitted to the bottle through a filter of cotton wool. It was carefully tested for chlorine by means of the nephelometer from time to time.

The sulphuric acid used for the preliminary drying of the gases was the usual "chemically pure" acid of the Laboratory, of a specific gravity of about 1.83. For the final drying this acid was boiled down in platinum.

Weighing.

The balance used was a long-armed Becker, sensitive to about one thirtieth of a milligram with the largest load that it was required to carry during the investigation, while the weights were a good set of gold plated ones, which were kept in the balance case under a glass cover. These weights were very carefully compared with one another, and all weighings were, of course, reduced to the vacuum standard. The specific

* See These Proceedings, XXVI. 249; XXX. 380.

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gravity of magnesic chloride used for this computation was the value 2.177 determined by Playfair and Joule. Weighing was done by substitution, the object to be weighed being placed on the right-hand pan and balanced by tare weights on the left. In general, the precautions used in the recent work done in this Laboratory upon copper, barium, strontium, and zinc were adhered to with great care.* We are indebted to the Cyrus M. Warren Fund of Harvard University for some of the platinum ware used in the following work.

The atomic weights used in this investigation were as follows: —

O . . .	16.000	Ag. . . .	107.930
Cl . . .	35.456		

Method of Work.

The method of operating may be inferred from the description of the apparatus. The platinum boat, after having been weighed within its weighing bottle, was filled with the double chloride of ammonium and magnesium and placed in position in the ignition tube, resting upon a sort of carriage of platinum foil. The weighing bottle was placed with its stopper in appropriate position in the "bottling tube," as previously described. A current of dry hydrochloric acid gas was then passed through the apparatus and the ignition tube was heated by a suitable arrangement of burners. At first the residual moisture was driven off by the heat and carried away by the stream of gas. When as much water as possible was expelled in this manner, the heat was slowly increased so that the ammonic chloride commenced to vaporize. It was found that the sublimation commenced before the salt was freed from the last traces of moisture, but an effort was always made, by the very gradual increase of heat, to make this proportion of water as small as possible; and it is probable that the salt was practically anhydrous some time before the last of the ammonic chloride was sublimed. When no further evolution of ammonic chloride could be observed, the heat was increased until the tube and boat were heated to redness, and the magnesic chloride had fused into a clear, colorless limpid liquid. It requires a very excellent piece of combustion tubing to stand the heat necessary to fuse magnesic chloride, and a number of tubes were spoiled during the course of the work. In the first series of determinations the boat was allowed to cool while the current of hydrochloric acid gas was still pass-

* Richards, These Proceedings, XXVI. 240; XXVIII. 1; XXIX. 55; XXX. 369; XXXI. 158.

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ing. The tubes containing the boat and weighing bottle were then thoroughly washed out with a current of air dried in an apparatus similar to that used for drying the hydrochloric acid gas, as previously described. After it was certain that all of the acid gas had been displaced, and while the current of air was passing rapidly to prevent any diffusion of moist air back into the apparatus, the bulbs were removed from the farther end of the ignition tube, and the boat was pushed into the bottle in the manner already described. The boat itself remained constant in weight during these operations, showing that the magnesic chloride had not acted upon it.

After weighing, the boat and its contents were placed in a large glass-stoppered Erlenmeyer flask, and the magnesic chloride was dissolved in pure water. The chlorine was precipitated with a dilute solution of argentic nitrate;* and after a thorough shaking the whole was allowed to stand in the dark over night. The argentic chloride was washed by decantation a number of times, with vigorous shaking, and was finally collected upon a Gooch crucible in the usual manner. The precipitate was dried from five to ten hours in an oven, carefully protected from dust and dirt, and weighed. After weighing, the cake of precipitate, together with some adherent asbestos, was removed to a tared porcelain crucible and heated until it began to fuse. The crucible was again weighed, and the loss of weight, if any, noted, and subtracted from the weight of the Gooch crucible and contents. The filtrate, containing a little dissolved argentic chloride, was evaporated down to small bulk and filtered through a very small filter; and the weight of the precipitate was added to the weight of the first portion. In some cases the small amount of argentic chloride present was determined with the nephelometer.†

The wash water from the precipitate collected on the Gooch crucible was also run through a small filter to make sure that no asbestos had been carried away from the crucible in the process of washing; and this correction, when appreciable, was applied in the appropriate place.

The washing and filtration were both performed in dim orange light, which had been suitably tested as to its non-actinic properties. Even after fusing the argentic chloride was almost colorless, showing that only unessential traces had been decomposed by the light.

The result of the first series of five experiments is given below. These

* This solution contained never more than one per cent of silver.

† See These Proceedings, XXX. 385.

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determinations were consecutive, except that one determination met with an accident and was not completed.

SERIES I.

No. of Exp.	Sample of $MgCl_2$ used.	Sample of Ag used.	Weight of $MgCl_2$.	Weight of AgCl.	Ratio. $MgCl_2 : 2\,AgCl = 100 : n$.	Atomic Weight of Mg.
1	1	1	1.33550	4.01952	300.975	24.368
2	1	1	1.51601	4.56369	301.033	24.350
3	1	1	1.32413	3.98528	300.974	24.369
4	1	1	1.40664	4.23297	300.928	24.384
5	1	1	1.25487	3.77670	300.963	24.373
					Average	24.369

A careful consideration of the possible constant errors involved in the foregoing results leads to the belief that the figures found are too high rather than too low, as the presence either of a small amount of water or of oxychloride in the magnesic chloride would tend in this direction.

Second Series of Determinations.

In order to drive all the subliming ammonic chloride to the farther end of the combustion tube during the ignition, it had been found necessary that the current of gas should be very considerable; and hence it was desirable to construct a piece of apparatus which should deliver the various gases rapidly, but nevertheless as dry as it is possible to obtain them. It was also desirable to work with larger quantities of materials than could be handled in the former apparatus. For these reasons another piece of apparatus was constructed to dry the hydrochloric acid gas; this apparatus contained several flasks of sulphuric acid, three very efficient towers containing the same acid, which was constantly renewed, and a long tube containing resublimed phosphoric pentoxide. One of the towers is shown on the following page. The whole apparatus was fused or ground together, thus wholly avoiding rubber or cork connections.

In the following determinations the boat was allowed to cool in an atmosphere of dry nitrogen, as a further precaution against a possible partial decomposition of the sensitive magnesic chloride. As soon as the

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salt had been fused, a current of dry nitrogen was passed into the combustion tube and the hydrochloric acid generator was disconnected. The nitrogen was prepared by passing mixed air and ammonia over rolls of copper gauze heated to redness, the excess of ammonia being removed by passing the gases through wash bottles containing dilute sulphuric acid; and the nitrogen was dried in a set of towers similar to those used for drying the current of air. When the tube was cool, the current of dry air was turned on, and the tube and its contents washed out as in previous experiments.

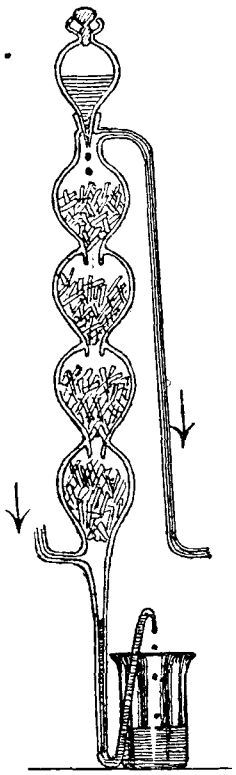

FIG. 3. — ONE OF THE TOWERS USED FOR DRYING HYDROCHLORIC ACID. Seventy centimeters high.

As there were no especial objections against the use of rubber connections and stoppers in the part of the apparatus used for drying the air, several large towers were employed, each filled with crushed pumice stone and saturated with sulphuric acid previous to using. Both air and nitrogen were finally dried by resublimed phosphoric pentoxide. The bottling and combustion tubes were of the same construction as in the former apparatus, except that they were larger.

In the second series, the method of igniting the double salt to obtain the magnesic chloride was the same as in the first; but the method of estimating the amount of chlorine present was different. From the approximate atomic weight of magnesium already found, a calculation was made as to the amount of silver necessary exactly to precipitate the chlorine present in the sample of magnesic chloride taken. This amount of silver was weighed out as nearly as possible, dissolved in nitric acid in an Erlenmeyer flask, provided with a set of bulbs to catch the spray from the evolution of gas, and added to the solution of magnesic chloride contained in a large flask. The flask was thoroughly agitated in the dark, and allowed to stand over night. Fifty cubic centimeters were then withdrawn by means of a pipette, and tested by means of a nephelometer, or apparatus for determining the amount of precipitate from the intensity of the opalescence produced by it. This piece of apparatus was con-

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structed for the purpose, and consisted of two rectangular glass cells, with a mirror enclosed in a dark case, so arranged that the column of liquid contained in the lower part of the cells could be viewed horizontally without disturbance from surface reflections. A dark screen was placed at the further end of the cells, and the whole so arranged that light could come to the eye only by reflection from solid particles which might be suspended in the column of liquid inspected. If the liquid was perfectly clear, the field of vision remained black, but an extremely small amount of precipitate produced a very marked change, and the intensity of opalescence was approximately proportional to the amount of precipitate. It was found perfectly easy and certain, by this method, to distinguish the difference between .002 and .003 of a milligram of argentic chloride or between .004 and .005 of a milligram, and larger amounts in proportion This instrument gave such satisfaction in this research that the method will be worked out for various other reactions, and published later.

The method of using this apparatus was as follows. Twenty-five cubic centimeters of the clear supernatant liquid from the flask containing the well shaken argentic chloride and magnesic nitrate were placed in each cell, five cubic centimeters of a very dilute solution of argentic nitrate being added to one, and five cubic centimeters of a correspondingly dilute solution of ammonic chloride to the other. The silver solution contained one milligram of silver to the cubic centimeter. An unequal depth of cloudiness indicated an excess of either silver or chlorine in the original solution, and accordingly the amount necessary for neutralization was run into the large flask containing precipitate and solution from a burette. The solution was again allowed to stand in the dark with occasional shaking, and after the precipitate had entirely subsided was again tested as before, and this cycle of operations was repeated until the opalescences matched one another.* It will be observed that, if water is added to the cell giving the more dense opalescence until the effect becomes equal on both sides, the amount of dilution will give a means of ascertaining the amount of precipitate in each cell. The appropriate corrections were then applied to the amount of silver taken. Due allowance was made for the slightly diminishing volume of the solution in the flask. The addition of one tenth of a milligram of silver to a litre of solution produced a distinct change in the depth of color observed. After the matching was completed, repeated trials were made with fresh

* For details of this method, see Stas, Mem. Acad. Belg., XLIII. Part II., and Richards, These Proceedings, XXIX. 86; XXX. 385.

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portions of the solution to confirm the result; and as the depth of opalescence as seen in the nephelometer was perfectly flat, without disturbing eflections, the end point could be determined with great precision.

Several results obtained in this manner are given in Series II.

SERIES II.

No. of Exp.	Sample of $MgCl_2$ used.	Sample of Ag used.	Weight of $MgCl_2$.	Weight of Ag.	Ratio. $MgCl_2 : 2\,Ag = 100 : n$.	Atomic Weight of Mg.
6	1	1	2.78284	6.30284	226.490	24.395
7	1	1	2.29360	5.19560	226.526	24.379
8	1	2	2.36579	5.35989	226.558	24.366
				Average		24.380

These results, however, do not merit great confidence; for the apparatus, which had become somewhat complicated, did not work smoothly at first, on account of some minor imperfections which were remedied later. Besides this, careful consideration led to the suspicion that the towers used for drying the air and nitrogen were not efficient enough to remove the last traces of water. Of necessity the towers had to be charged with sulphuric acid an hour or two before their final use, and during that time a large part of the acid drained out of the pumice stone. This surmise was fully confirmed by later experiments; and since this was the case, the second series must be rejected in the final estimate of the atomic weight.

Third Series of Determinations.

In order to remedy the most serious defect of the second series, the arrangement for drying the air and nitrogen was much enlarged and improved. By pouring sulphuric acid into the safety funnels at the top of the many towers, from time to time, during the passage of the gas, the glass beads were kept thoroughly saturated during the whole process. The sulphuric acid having reached the bottom of the column drained out of the tubes provided for that purpose into beakers below. It will be seen that by this means the efficiency of the apparatus was far greater than in the previous form. As a test, a very rapid stream of wet air

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from a water blast was passed through the apparatus and then through a weighed phosphorus pentoxide bulb for nearly two hours, without the slightest appreciable increase of weight of the pentoxide bulb. The same test was applied to the apparatus for drying the hydrochloric acid gas, with the same result.

With the help of this important addition to the apparatus, another series of determinations was now made. The somewhat lower result of this series is undoubtedly due to the more perfect desiccation of the gases; the agreement of the individual results is still not quite perfect, but the series is undoubtedly far more reliable than the second.

SERIES III.

No. of Exp.	Sample of $MgCl_2$ used.	Sample of Ag used.	Weight of $MgCl_2$.	Weight of Ag.	Ratio. $MgCl_2 : 2\,Ag = 100 : n$.	Atomic Weight of Mg.
9	1	2	1.99276	4.51554	226.597	24.349
10	1	2	1.78870	4.05256	226.565	24.363
11	1	2	2.12832	4.82174	226.551	24.369
12	2	2	2.51483	5.69714	226.542	24.373
13	2	3	2.40672	5.45294	226.571	24.360
14	2	3	1.95005	4.41747	226.531	24.377
				Average		24.365

Fourth and Final Series of Determinations.

The apparatus was now put in the best possible order, and the phosphorous pentoxide tubes were recharged, in order to make ready for a series of determinations in which the very highest exactness was to be aimed at. The purest samples of material were used, and all other precautions, learned from previous work, were taken to insure accuracy. The following determinations were consecutive, with the exception of one between Nos. 15 and 16, which was spoiled by a slight accident.

These results agree with one another as well as could possibly be expected, for the difference between the extremes in the last series corresponds to a difference of only one tenth of a milligram in the weight of the magnesic chloride. Since two wholly distinct samples of this salt

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SERIES IV.

No. of Exp.	Sample of $MgCl_2$ used.	Sample of Ag used.	Weight of $MgCl_2$.	Weight of Ag.	Ratio. $MgCl_2 : 2\,Ag = 100 : n$.	Atomic Weight of Mg.
15	2	3	2.03402	4.60855	226.573	24.360
16	2	3	1.91048	4.32841	226.562	24.364
17	2	3	2.09932	4.75635	226.566	24.362
18	2	2	1.82041	4.12447	226.568	24.362
19	2	2	1.92065	4.35151	226.565	24.363
20	3	4	1.11172	2.51876	226.564	24.363
					Average	24.362
					Extreme difference . .	0 004

and three wholly distinct samples of silver were used in this series, we may conclude that all ordinary accidental errors had been eliminated; and in a critical discussion of the result we may limit ourselves to the consideration of the possible constant errors of the process.

The most serious objection to the method is, of course, the possible retention of water, of magnesic oxychloride, or of ammonic chloride by the magnesic salt.

With regard to the first two difficulties, it need only be said that the gases used for drying the magnesic chloride were as dry as present possibilities permit them to be made. The phosphorus pentoxide in the last drying tube showed no trace of liquefaction at the close of the research, but seemed to be as light and powdery as at first, in spite of the fact that several hundred litres of gas had been passed over it. Any trace of oxygen, as well as of aqueous vapor, was excluded from the hot salt; for the hydrochloric acid gas was replaced by nitrogen, and this was driven out in its turn by dry air only after the tube had cooled. A means of proving absolutely that no water remained does not exist; but it is extremely hard to see how water could have gained access to the carefully guarded magnesic chloride.

The fact that every sample of magnesic chloride used in the last series gave an absolutely clear and transparent solution in water is additional evidence of much weight; for a very small trace of oxychloride would

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have shown itself in opalescence. As a proof of this it may be stated that in experiment No. 12 of Series III. there was a perceptible cloudiness upon the solution of the magnesic chloride in water, owing to a known access of a trace of aqueous vapor, caused by a momentary stoppage of the current of nitrogen. This result is, however, scarcely at all different from the others.

With regard to the possible retention of ammonic chloride by the magnesium salt, it may be said: first, that none could be detected by means of a Nessler solution; and, secondly, that even if a small amount had been retained, it would have made but a very slight difference in the final result.

Our result is essentially the same, no matter whether the chlorine is weighed as argentic chloride (Series I.), or the amount of silver necessary to precipitate it is found (Series III. and IV.). This fact is satisfactory evidence that that silver and chlorine were both pure, as well as that no magnesic chloride was occluded by the argentic chloride. Thus: —

From the ratio $2\,AgCl : MgCl_2$ (Series I.), $Mg = 24.369$.
" " $2\,Ag : MgCl_2$ (Series III.), $Mg = 24.365$.
" " $2\,Ag : MgCl_2$ (Series IV.), $Mg = 24.362$.

Upon comparing these figures with the older ones, they are seen to agree surprisingly with Marignac's value obtained from work upon magnesic oxide and sulphate ($Mg = 24.37$). Burton and Vorce's syntheses of magnesic oxide gave a lower value for magnesium (24.28); but if these were corrected for a probable amount of gases in the magnesic oxide, the result would probably be close to the present one. The analytical chemist should not forget that the value 24.36 is one and a half per cent higher than the round number 24, which has been so commonly accepted.

For reasons which must be manifest to any careful reader of the foregoing paper, we accept the value given by the fourth and last of our series as representing the most probable atomic weight of magnesium. It remains only to state this result in terms of the usual unfortunately varying standards of reference used by the scientific world.

If $O = 16.000$, $Mg = 24.362$.
If $O = 15.96$, $Mg = 24.301$.
If $O = 15.88$, $Mg = 24.179$.

CAMBRIDGE, May 1, 1896.

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ON THE GROUP OF REAL LINEAR TRANSFORMATIONS WHOSE INVARIANT IS A REAL QUADRATIC FORM.

By Henry Taber.

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ON THE GROUP OF REAL LINEAR TRANSFORMATIONS WHOSE INVARIANT IS A REAL QUADRATIC FORM.

By Henry Taber.

Presented May 13, 1896.

In what follows G will denote the group of real linear homogeneous transformations of determinant $+1$ whose invariant is the real quadratic form of non-zero determinant,

$$\mathfrak{F} = (\Omega \, \S \, x_1, x_2, \ldots x_n)^2,$$

where Ω is a real symmetric matrix.*

Since the quadratic form $\mathfrak{F}$ is real, the roots of its characteristic equation are all real. In the *Proceedings of the London Mathematical Society*, Vol. XXVI., page 376, I have shown that for $n = 4$ the group of all proper linear homogeneous transformations, real and imaginary, whose invariant is the real quadratic form $\mathfrak{F}$, provided the roots of the characteristic equation of $\mathfrak{F}$ are not all of the same sign, contains a *real* transformation that cannot be generated by the repetition of any infinitesimal transformation of this group; and that therefore, *a fortiori*, cannot be generated by the repetition of an infinitesimal transformation of group G. It follows that for $n > 4$ not every transformation of group G can be generated by the repetition of an infinitesimal transformation of group G if the roots of the characteristic equation of $\mathfrak{F}$ are not all of the same sign.

On the other hand, if the roots of the characteristic equation of $\mathfrak{F}$ are all positive or all negative, every transformation of group G can be generated by the repetition of an infinitesimal transformation of this group.†

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* I employ the notation of Cayley's "Memoir on the Automorphic Linear Transformation of a Bipartite Quadric Function," *Philosophical Transactions*, 1858, with this exception: the transverse of a matrix or linear transformation ϕ will be denoted by $\breve{\phi}$.

† If the roots of the characteristic equation of $\mathfrak{F}$ are all of the same sign, group G is isomorphic with the group of real proper orthogonal substitutions; and every

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I shall therefore assume that $n \geqq 4$, that the roots of the characteristic equation of $\mathfrak{F}$ are not all of the same sign; and I shall show that a transformation of group G can be generated by the repetition of an infinitesimal transformation of group G if it is an even power of a transformation of this group.

If the matrix or linear homogeneous transformation ϕ transforms $\mathfrak{F}$ automorphically, it satisfies the matrical equation

$$\breve{\phi}\ \Omega\ \phi = \Omega, \tag{1}$$

in which $\breve{\phi}$ denotes the transverse or conjugate of ϕ. Conversely, if this equation is satisfied, ϕ transforms $\mathfrak{F}$ automorphically. The determinant of any transformation satisfying this equation is equal to either $+1$ or -1. By definition the totality of real proper solutions of equation (1) constitutes group G.

If ϕ is any real solution of equation (1), we may put

$$\phi = \phi_0\,\phi_1 = \phi_1\,\phi_0,$$

where ϕ_0, ϕ_1, are polynomials in ϕ, are both real, and are both solutions of equation (1), that is

$$\breve{\phi}_0\ \Omega\ \phi_0 = \Omega, \qquad\qquad \breve{\phi}_1\ \Omega\ \phi_1 = \Omega.$$

Moreover -1 is not a root of the characteristic equation of ϕ_1, therefore the determinant of ϕ_1 is equal to $+1$;* and consequently ϕ_1 is a transformation of group G. Finally,

$$\phi_0^{\,2} = 1;$$

and therefore

$$\phi^2 = \phi_0^{\,2}\,\phi_1^{\,2} = \phi_1^{\,2}. \tag{2}$$

That is, the second power of any real solution of equation (1) is the second power of a transformation of group G.†

---

transformation of this group can be generated by the repetition of a real infinitesimal orthogonal transformation.

* The roots, other than ± 1, of the characteristic equation of any solution of equation (1) occur in pairs, the product of two of the same pair being unity. The determinant of a linear transformation is equal to the product of the roots of its characteristic equation.

† If -1 is a root of multiplicity m of the characteristic equation of ϕ, and if the roots of this equation other than -1 are g_1, g_2, etc. of multiplicity, respectively, p_1, p_2, etc., then

$$\phi_0 = 1 - 2\,\Phi,$$

where

$$\Phi = \frac{[(\phi-1)^m - (g_1+1)^m]^{p_1}}{[-(g_1+1)^m]^{p_1}} \cdot \frac{[(\phi+1)^m - (g_2+1)^m]^{p_2}}{[-(g_2+1)^m]^{p_2}} \cdots$$

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Let now e^{χ} denote the infinite series

$$1 + \chi + \frac{1}{2!}\chi^2 + \frac{1}{3!}\chi^3 + \text{etc.},$$

convergent for any finite matrix. We have

$$(e^{\chi})^{-1} = e^{-\chi},$$
$$\breve{(e^{\chi})} = e^{\breve{\chi}},$$

and for any integer m,

$$(e^{\chi})^m = e^{m\chi};$$

moreover, if χ and χ' are commutative,

$$e^{\chi+\chi'} = e^{\chi}\, e^{\chi'} = e^{\chi'}\, e^{\chi}.$$

Corresponding to any finite matrix, ϕ, of non-zero determinant can be found a polynomial χ in ϕ such that

$$\phi = e^{\chi}.$$

The infinite series

$$1 - \frac{1}{2!}\chi^2 + \frac{1}{4!}\chi^4 - \text{etc.}$$

and

$$\chi - \frac{1}{3!}\chi^3 + \frac{1}{5!}\chi^5 - \text{etc.}$$

are also convergent for any finite matrix, and are equal respectively to

$$\frac{1}{2}(e^{\chi\sqrt{-1}} + e^{-\chi\sqrt{-1}}), \quad \frac{1}{2\sqrt{-1}}(e^{\chi\sqrt{-1}} - e^{-\chi\sqrt{-1}}).$$

Therefore, if χ and $e^{\chi\sqrt{-1}}$ are both real, the second power of the latter is equal to the identical transformation. For if χ and $e^{\chi\sqrt{-1}}$ are real,

$$e^{\chi\sqrt{-1}} - e^{-\chi\sqrt{-1}} = 0;$$

that is,

$$(e^{\chi\sqrt{-1}})^2 = 1.$$

Since the determinant of ϕ_1 is not zero, by what precedes, a polynomial χ in ϕ_1 can be found such that

$$\phi_1 = e^{\chi};$$

and since -1 is not a root of the characteristic equation of ϕ_1, χ may be so chosen that, if

$$\vartheta = \chi\,\Omega^{-1},$$

we shall have

$$\breve{\vartheta} = -\vartheta,$$

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that is, ϑ is skew symmetric. If now

$$\vartheta = \theta + \eta\sqrt{-1},$$

where θ and η are real, both θ and η are skew symmetric, that is,

$$\breve{\theta} = -\theta, \quad \breve{\eta} = -\eta. \tag{3}$$

Since Ω is real, $\theta\Omega$ and $\eta\Omega\sqrt{-1}$ are the real and imaginary parts respectively of $\vartheta\Omega = \chi$. And since the latter is a polynomial in the real matrix ϕ_1, its real and imaginary parts, $\theta\Omega$ and $\eta\Omega\sqrt{-1}$, are polynomials in ϕ_1, and are therefore commutative. Consequently, by virtue of a theorem given above,

$$\begin{aligned}\phi_1 &= e^{\chi} \\ &= e^{\vartheta\Omega} \\ &= e^{\theta\Omega + \eta\Omega\sqrt{-1}} = e^{\theta\Omega}\, e^{\eta\Omega\sqrt{-1}}.\end{aligned}$$

Since ϕ_1 is real, and since $\theta\Omega$ and therefore $e^{\theta\Omega}$ is real, it follows that $e^{\eta\Omega\sqrt{-1}}$ is real. Therefore, by what precedes, since $\eta\Omega$ is real,

$$(e^{\eta\Omega\sqrt{-1}})^2 = 1.$$

Whence we have

$$\phi_1{}^2 = (e^{\theta\Omega})^2 (e^{\eta\Omega\sqrt{-1}})^2 = (e^{\theta\Omega})^2 = e^{2\theta\Omega};$$

and therefore by (2)

$$\phi^2 = \phi_1{}^2 = e^{2\theta\Omega}.$$

If now we put

$$\psi = e^{\frac{2}{m}\theta\Omega},$$

where m is any positive integer, ψ is real, and

$$\psi^m = (e^{\frac{2}{m}\theta\Omega})^m = e^{2\theta\Omega} = \phi^2.$$

Moreover, since $\breve{\Omega} = \Omega$, and since, by (3), $\breve{\theta} = -\theta$, we have

$$\breve{\psi} = e^{\frac{2}{m}\breve{\theta}\breve{\Omega}} = e^{\frac{2}{m}\breve{\Omega}\breve{\theta}} = e^{-\frac{2}{m}\Omega\theta};$$

and therefore

$$\begin{aligned}\breve{\psi}\,\Omega\,\psi &= e^{-\frac{2}{m}\Omega\theta}\,\Omega\, e^{\frac{2}{m}\theta\Omega} \\ &= \Omega\, e^{-\frac{2}{m}\theta\Omega}\, e^{\frac{2}{m}\theta\Omega} = \Omega.*\end{aligned}$$

---

* For any positive integer p,

$$(\Omega\theta)^p\,\Omega = \Omega\,(\theta\Omega)^p.$$

Therefore

$$e^{-\frac{2}{m}\Omega\theta}\,\Omega = \Omega\, e^{-\frac{2}{m}\theta\Omega}.$$

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Finally, we may show in precisely the same way that $e^{\frac{1}{m}\theta\Omega}$ is a real solution of equation (1); and therefore, since $(e^{\frac{1}{m}\theta\Omega})^2 = e^{\frac{2}{m}\theta\Omega}$, it follows that ψ is the second power of a solution of equation (1), and is thus of determinant $+1$. Wherefore, ψ is a transformation of group G.*

By taking m sufficiently great, $\frac{2}{m}\theta\Omega$ may be made as nearly as we please equal to zero, and therefore $\psi = e^{\frac{2}{m}\theta\Omega}$ may be made as nearly as we please equal to the identical transformation. Wherefore, $\phi^2 = \phi_1^2$ can be generated by the repetition of an infinitesimal transformation of group G.

The converse is of course also true; that is to say, every transformation generated by the repetition of an infinitesimal transformation of group G is the pth power (for any positive integer p), and therefore the second power, of a transformation of this group. This may be shown as follows. The transformation ϕ, if infinitesimal, may be put equal to $1 + \delta t \cdot \chi$, where δt is infinitesimal. If ϕ is a transformation of group G, δt and χ are both real, and we have

$$(1 + \delta t \cdot \breve{\chi})\,\Omega\,(1 + \delta t \cdot \chi) = \breve{\phi}\,\Omega\,\phi = \Omega .$$

That is, neglecting terms involving the second power of δt,

$$\breve{\chi}\,\Omega + \Omega\,\chi = 0 .$$

If we put $\theta = \chi\,\Omega^{-1}$, θ is real, and the preceding equation becomes

$$\Omega\,\breve{\theta}\,\Omega + \Omega\,\theta\,\Omega = 0 ;$$

that is,

$$\breve{\theta} = -\theta .$$

The transformation resulting from m repetitions of the infinitesimal transformation

$$\phi = 1 + \delta t \cdot \chi = 1 + \delta t \cdot \theta\,\Omega$$

is the transformation $(1 + \delta t \cdot \theta\,\Omega)^m$, which, if m is infinite, is equal to $e^{m\,\delta t \cdot \theta\Omega}$, or $e^{t\,\theta\Omega}$ if we put $t = m\,\delta t$. The repetition of an infinitesimal transformation of group G results in a transformation of this group; and therefore, as we have in fact already seen, $e^{t\,\theta\Omega}$ for any real quantity t is a

* The matrix $e^{\frac{1}{m}\theta\Omega}$ is also a transformation of group G. The totality of transformations $e^{\frac{1}{m}\theta\Omega}$ for all possible real values of m constitutes a continuous one term sub-group which contains the identical transformation.

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transformation of group G. But then $e^{\frac{t}{p}\theta\Omega}$, for any positive integer p, is a transformation of group G; and since $(e^{\frac{t}{p}\theta\Omega})^p = e^{t\theta\Omega}$, any transformation generated by the repetition of an infinitesimal transformation of group G is the pth power, for any integer p, of a transformation of this group.

It may be shown that any transformation of group G that cannot be generated by the repetition of an infinitesimal transformation of group G is the $(2p+1)$th power of a transformation of this group for any integer p.

For any transformation of group G that can be generated by the repetition of an infinitesimal transformation of group G, the numbers belonging to each negative root of the characteristic equation are all even.*

Postscript.

Let $\mathfrak{G}$ denote the group of all linear homogeneous transformations, real and imaginary, of determinant $+1$ whose invariant is the real quadratic form of non-zero determinant,

$$\mathfrak{F} = (\Omega)(x_1, x_2, \ldots x^n)^2;$$

and, as above, let G denote the sub-group of real transformations of group $\mathfrak{G}$.

A transformation of group $\mathfrak{G}$ can be generated by the repetition of an infinitesimal transformation of this group if -1 is not a root of the characteristic equation of the transformation, or if -1 is a root of the characteristic equation, provided the numbers belonging to -1 are all even.†

As stated above, if a transformation of group G can be generated by the repetition of an infinitesimal transformation of this group, the numbers belonging to each negative root of the characteristic equation of the transformation are all even. These conditions, though necessary, are not always sufficient. Thus, for $n = 2$, the form $\mathfrak{F}$ is transformed automorphically if

$$x'_1 = -x_1, \quad x'_2 = -x_2;$$

---

* For definition of the numbers belonging to a root of the characteristic equation of a transformation, see These Preceedings, Vol. XXXI. p. 336.

† *Proceedings of the London Mathematical Society*, Vol. XXVI. p. 374.

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and this transformation of group G, if the roots of the characteristic equation of $\mathfrak{F}$ are not both of the same sign, is not the second power of any transformation of group G, and therefore cannot be generated by the repetition of an infinitesimal transformation of this group. Since the numbers belonging to -1 are all even, the transformation defined by the above equations can be generated by the repetition of an infinitesimal transformation of group $\mathfrak{G}$.

July 28, 1896.

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CONTRIBUTIONS FROM THE ZOÖLOGICAL LABORATORY OF THE MUSEUM OF COMPARATIVE ZOÖLOGY AT HARVARD COLLEGE, E. L. MARK, DIRECTOR, No. LXXIII.

STUDIES IN MORPHOGENESIS, VI.

A CONTRIBUTION TO THE QUANTITATIVE STUDY OF CORRELATED VARIATION AND THE COMPARATIVE VARIABILITY OF THE SEXES.

By C. B. Davenport and C. Bullard.

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CONTRIBUTIONS FROM THE ZOÖLOGICAL LABORATORY OF THE MUSEUM OF COMPARATIVE ZOÖLOGY AT HARVARD COLLEGE, E. L. MARK, DIRECTOR, No. LXXIII.

STUDIES IN MORPHOGENESIS, VI.

A CONTRIBUTION TO THE QUANTITATIVE STUDY OF CORRELATED VARIATION AND THE COMPARATIVE VARIABILITY OF THE SEXES.

By C. B. Davenport and C. Bullard.

Presented October 14, 1896.

The following quantitative study of variation is based upon counts of the Müllerian glands of the fore legs of 4,000 swine. Our attention was directed to these glands as favorable objects of study by Gertrude Crotty Davenport, who had already collected some data concerning their variability. These data, together with valuable suggestions derived from her own experience, she generously placed at our disposal.

The positions of the Müllerian glands are indicated upon the wrist by large openings or pits, about 1 mm. in diameter, which are found only upon the inner aspect of the fore legs. The number of pits is variable. Where there are several they occur, for the most part, in a single row trending somewhat obliquely to the long axis of the leg.

Of the 8,000 legs examined, the arrangement of the glands was studied on only 2,000 legs, 1,000 male and 1,000 female. The total number of glands on a single leg varies from 0 to 10. When the number is large, some of the glands are frequently found outside the main row. In no case have we found more than nine glands in one row. We may call those lying outside the main row *lateral* glands. The lateral glands usually (six exceptions) occur at the upper (proximal) end of the series. Their number does not usually exceed two, but in a single case we have found four. These four glands lay in a secondary row parallel to the main row, which contained five glands. In one other case, where three lateral glands were found, these lay parallel to the main row of five. When there are two glands they may lie either in a line parallel with the main row, or make any angle up to 90° with it. Lateral glands occur more rarely when the total number of glands on the leg is small, but we have found one extreme case in which the only two glands on the leg occurred side by side, i. e. in a transverse row.

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The reduction in the number of glands takes place from one end, — the distal end of the series. Generally, where there are only two or three glands these occur high up and the normal diatance apart. Rarely, however, the reduction is brought about in part by the failure to develop in the middle of the series while glands develop near the extremes, so that there is a broad hiatus in the series.

Since the proximal end of the series is that at which glands are most likely to be formed, and since they tend to be produced more abundantly there, this end, which occupies the region of the upper wrist, is to be considered as the source of the morphogenic impulses which give rise to the glands. Sometimes the embryonic Anlage does not develop beyond this point; sometimes, on the other hand, it develops along the whole extent of the wrist in one row, and even forms an accessory "lateral" row.

The total number of swine examined was, as stated, 4,000; of which 2,000 were males and 2,000 females. The total number of fore legs examined was, accordingly, 8,000; 4,000 left and 4,000 right. All of the observations fall, consequently, into four groups of 2,000 cases each; namely, male right, male left, female right, female left. These four groups will be considered, for the most part, separately.

We first determined how many legs in each of these classes had no glands, one gland, two glands, and so on. The results are given in the following table.

TABLE I.

No. of Glands.	0	1	2	3	4	5	6	7	8	9	10	Total.
♂ R	15	225	353	437	411	297	155	78	16	12	1	2,000
♂ L	14	241	336	430	429	295	159	53	30	10	3	2,000
Total ♂	29	466	689	867	840	592	314	131	46	22	4	4,000
♀ R	15	209	365	482	414	277	134	72	22	8	2	2,000
♀ L	21	213	361	438	432	288	149	69	16	11	2	2,000
Total ♀	36	422	726	920	846	565	283	141	38	19	4	4,000
Total ♂ + ♀	65	888	1415	1787	1686	1157	597	272	84	41	8	8,000

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In the following table, which is based upon the preceding, the numbers are all reduced to per milles. The two lines of totals are here, accordingly, replaced by means. A glance at this table shows a close parallelism between the distribution of glands in the four cases.

TABLE II.

SUMMARY PER MILLE.

No. of Glands.	0	1	2	3	4	5	6	7	8	9	10
♂ R	7.5	112.5	176.5	218.5	205.5	148.5	77.5	39.0	8.0	6.0	0.5
♂ L	7.0	120.5	168.0	215.0	214.5	147.5	79.5	26.5	15.0	5.0	1.5
Mean ♂	7.2	116.5	172.2	216.8	210.0	148.0	78.5	32.8	11.5	5.5	1.0
♀ R	7.5	104.5	182.5	241.0	207.0	138.5	67.0	36.0	11.0	4.0	1.0
♀ L	10.5	106.5	180.5	219.0	216.0	144.0	74.5	34.5	8.0	5.5	1.0
Mean ♀	9.0	105.5	181.5	230.0	211.5	141.3	70.7	35.2	9.5	4.7	1.0
Mean of ♂ and ♀	8.1	111.0	176.8	223.4	210.7	144.7	74.6	34.0	10.5	5.1	1.0

Several interesting questions now arise:

(1) How closely similar is the average number of glands in the two sexes, and in the right and left leg of the same sex?

(2) Which sex shows the greater variability, and to what extent is it greater? Is the relation between the variability of the right and left legs closer than that between the two sexes?

(3) How closely correlated are the numbers of glands on the right and left legs of individuals? That is to say, what are the chances that a swine which has 2, 4, or 7 glands on the right leg will have the same number on the left leg also?

1. *The Relation between the Abundance of Glands and the Sex or the Side of the Body.*

The average number of glands on a leg of either sex is determined by dividing the total number of glands counted in that leg by the number of individuals of that sex, in this investigation 2,000. This gives us the following result: —

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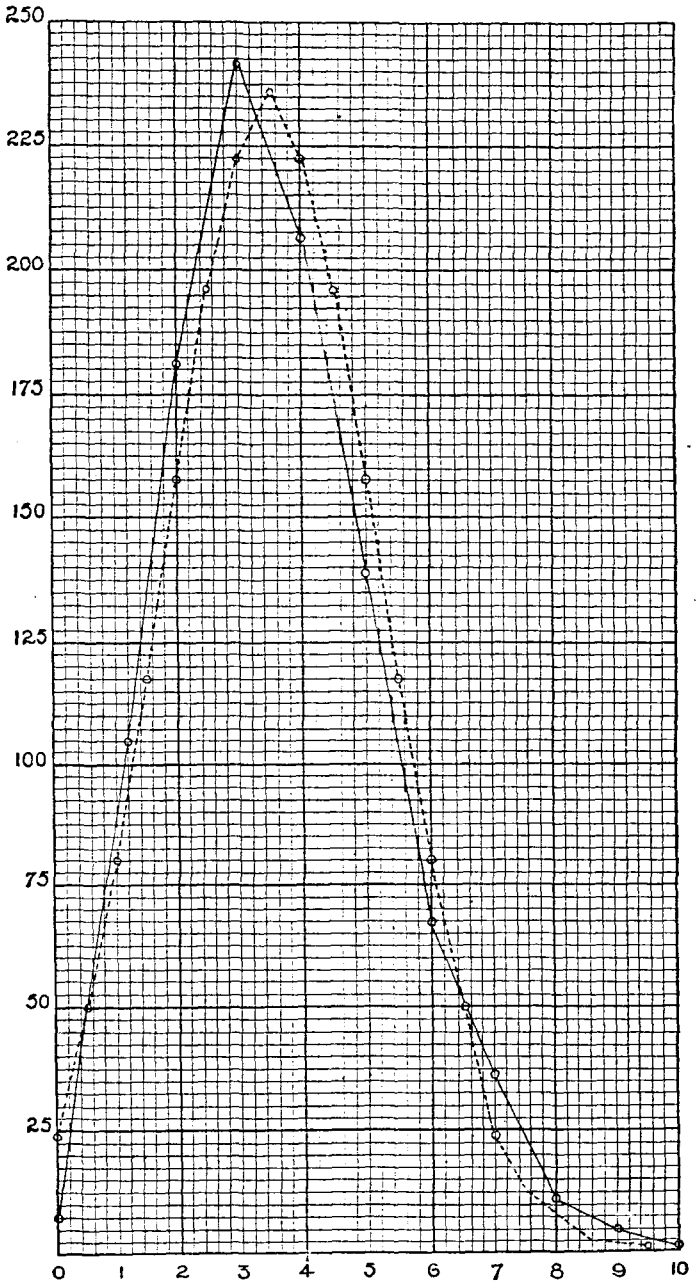

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1.	Average number	of	glands	in ♂ R	3.547
2.	"	"	"	♂ L	3.540
3.	"	"	"	♀ R	3.501
4.	"	"	"	♀ L	3.521

Comparing the average of (1) and (2) with the average of (3) and (4) it appears that the average number of glands in the males (3.544) is tolerably close to that in the females (3.511) but that a real difference exists between the two. *The glands are slightly less abundant in the female than in the male in the ratio*, 100 : 100.94. The average number of glands on the right side of the body is so close to that on the left side (3.524 : 3.531) that we may conclude: *The average numbers of the glands on the right leg and on the left leg taken without regard to sex are about equal.*

2. *Variability correlated with the Sex and with the Side of the Body.*

In seeking to determine whether, in this matter of glands, male or female swine are the more variable, it is necessary to employ a method of stating variability quantitatively. Quetelet, Stieda, and Galton * have employed such a method, based upon the fact that the organs of an animal vary about their mean dimensions to an extent and with a frequency indicated by the probability-of-error equation,†

$$y = k \cdot e^{-h^2x^2}.$$

Two of the principal features involved in such a distribution are that deviations of a given size are equally apt to occur above and below the mean, and that small deviations are more apt to occur than large ones. These and other characters of the "probability" curve are indicated in that shown in dotted line in the accompanying diagram. The diagram also shows the curve of distribution of the various numbers of glands occurring on a leg, from 1 to 10. This curve is drawn from the right female leg only; the curve for the other legs would be very similar. We shall speak in a moment of the method of construction of these curves; but we want now to call attention to the fairly close similarity of the two curves, — that gained by observation and the theoretical one, — a similarity so close that we are justified in concluding that the law of distribution of the variants in the leg glands of swine is the same as that of accidental errors.

* Quetelet, Lettres sur la théorie des probabilités, Bruxelles, 1846. Stieda, in Archiv für Anthropologie, Bd. XIV. pp. 167–182. Galton, Natural Inheritance, New York and London, 1889.

† See any text-book on "Least Squares."

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This being granted, we can express quantitatively the degree of variation in the glands by determining the *average deviation* in the number of glands of any set of legs from the mean number of that set. Thus in the right leg of the female the mean number of glands is approximately 3.5. Since there is no individual with 3.5 glands on the leg, every individual shows in the number of its leg glands a departure of at least 0.5 from the mean. Adding together the departures of every individual and dividing by the total number of individuals (2,000) we get the mean departure, which is known to mathematicians as the mean error, and is indicated by the formula $\frac{\Sigma x}{n}$, in which Σx indicates the *sum* of the individual departures, x, and n the total number of individuals. Proceeding in this way, the average departure, as an *Index of Variability,* was determined to be as follows for each set of legs: —

Average departure of			♂ R	1.41089
"	"	"	♂ L	1.41083
"	"	"	♀ R	1.36457
"	"	"	♀ L	1.38766

These determinations indicate that the variability of the right and the left legs, of the male is exactly the same to four places of decimals; that the variability of the right leg of the female is slightly less than that of the left leg, and that the male shows a greater variability than the female in the ratio of about 1.411 : 1.376, or 1.025 : 1.000. In other words, the male is 2.5% more variable than the female.

As we have seen, the variabilities of the right and of the left sides of the male are practically equal. In the female, the left side is more variable. Disregarding sex, we find the variability of the left side is to that of the right as 1.3993 : 1.3877, or as 1.0084 : 1. That is to say, the glands are 0.8% more variable on the left side than on the right.

Let us now compare the relative variability of symmetrical legs with that of the two sexes. We find the variability to be greater between the same leg (say the right) in opposite sexes, than between symmetrical legs. The relation may be expressed by the ratio 1.025 : 1.0084, or 1.016 : 1. These numbers indicate a closer morphogenetic kinship between the two legs of a symmetrical pair than between the corresponding leg in different sexes.

We may now briefly indicate the method of constructing the probability curve in the diagram. The abscissas represent the numbers of glands from 0 to 10 on a leg, and the ordinates the corresponding number

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of individuals per mille. The mean number of glands is 3.50 and the index of variability is 1.3646. With these data, we can draw a probability curve including about the same area as our observed curve. This curve, the continuous line, is drawn from the equation

$$y = k \cdot e^{-h^2 x^2}.$$

h is the so called index of precision, and is equal to the reciprocal of the index of variability divided by the square root of π, thus,

$$h = \frac{n}{\Sigma x \sqrt{\pi}}.$$

e is the base of the Napierian system of logarithms; namely, 2.1718.

k is a constant determined by multiplying the quotient of $\frac{h}{\sqrt{\pi}}$ by the interval (dx) between successive values of x, in this case, 1; thus,

$$k = \frac{h\,dx}{\sqrt{\pi}}.$$

x indicates deviations from the mean value, and y the corresponding ordinates.

When $x = 0$, $y = k$, which is thus the length of the ordinate at the mean value of x. Its value gives the percentage of cases which should theoretically occur at the mean; it is in this case 23.3%. Like h, k might be taken as a measure of precision, since it increases as variability diminishes.

3. *The Degree of Correlation between the Number of Glands on the Right and the Left Legs of Individuals.*

To get quantitative results in this matter we must employ a method devised by Galton.* This method depends upon the following procedure and considerations. Separate the right legs into as many lots as there are degrees of deviation from the mean number of glands. These lots may be called the subjects. Find for each of the subjects the mean deviation in the number of glands on the left legs of the corresponding individuals (the relative). The deviation of any subject and the deviation of the corresponding relative are to be compared. In order to make this comparison instructive, we must take into account the fact that left legs (for example) are more variable than right legs. In order to eliminate this

* Galton's method is explained in his paper in the Proc. Roy. Soc., Vol. XLV. p. 135, 1889.

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difference, divide the deviation of the subjects by their index of variability and the deviation of the corresponding relatives by their index of variability. If now, the correlation is perfect, those causes which have produced a deviation from the mean in the right leg will act in precisely the same degree on the left leg also, and thus the deviation of any relative will not differ from the deviation of the corresponding subject. If, under these circumstances, we divide the mean deviation of the relatives by that of the subjects, the quotients will average 1. This average quotient is called the Index of Correlation. Thus, the index of perfect correlation is 1.

Let us suppose, on the contrary, that there is no correlation whatever between the number of glands in any subject and in the corresponding relative, then, no matter what the number of glands in any subject, the number in the corresponding relative is just as apt to be large as small, and will be equal to the average number of glands in the whole group; in other words, no matter what the deviation of the subject is, that of the relative will be 0. The average quotient obtained, under these circumstances, by dividing the deviation of relatives by the deviation of the subjects, will consequently always be 0. Thus the index of entire lack of correlation is 0.

An inverse correlation, in which a positive deviation of the subject from the mean shall always be accompanied by a negative deviation of the relative, will be represented by a minus quantity. Thus the correlation of any two sets of compared organs will lie between +1 and —1. The size of the fractions lying between ±1 and 0 will serve to indicate the degree of correlation.

The quotient, r, obtained by dividing the deviation (always in units of the average deviation) of the left legs by that of the corresponding right will not be the same for all the lots of individuals. The true index of correlation, R, will be found by taking the average of all the ratios, r, r', r'', r''', etc. This process of finding R may be somewhat abbreviated from the following considerations. We have seen that

$$r = \frac{\dfrac{\text{Deviat. of Rel.}}{\text{Avg. Dept. of Rel.}}}{\dfrac{\text{Deviat. of Subj.}}{\text{Avg. Dept. of Subj.}}} = \frac{\dfrac{d_r}{A_r}}{\dfrac{d_s}{A_s}};$$

also that

$$R = \frac{1}{n}(r + r' + r'' + \ldots . r^n) = \frac{1}{n}\Sigma r;$$

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consequently,

$$R = \frac{1}{n}\left(\frac{\frac{d_r}{A_r}}{\frac{d_s}{A_s}} + \frac{\frac{d'_r}{A_r}}{\frac{d'_s}{A_s}} + \frac{\frac{d''_r}{A_r}}{\frac{d''_s}{A_s}} + \cdots \frac{\frac{d^n_r}{A_r}}{\frac{d^n_s}{A_s}}\right) = \frac{1}{n}\Sigma\frac{\frac{d_r}{A_r}}{\frac{d_s}{A_s}} = \frac{A_s}{A_r}\cdot\frac{1}{n}\cdot\Sigma\frac{d_r}{d_s}.$$

since A_s and A_r are constant. It results from this that it is only necessary to find the mean of the ratios of the untransmuted deviations and multiply this by the quotient $\frac{A_s}{A_r}$. This saves a great many divisions, and it has been the method pursued in our work.

After this statement of the method of expressing correlation we now pass to a consideration of the results obtained with the glands of the pig. We shall consider first the correlation between the number of glands on the right leg of the male with that on the left leg of the male.

TABLE III.

♂ R CORRELATED WITH ♂ L.

Relatives. Subjects.	0*l*	1*l*	2*l*	3*l*	4*l*	5*l*	6*l*	7*l*	8*l*	9*l*	10*l*	No. of Indivs. Right leg.	Means of Lefts.	Dev. of Rel. (d_r)	Dev. of Sub. (d_s)	$\frac{d_r}{d_s}$ Quo.
0*r*	8	5	2	—	—	—	—	—	—	—	—	15	0.600	−2.940	−3.547	.829
1*r*	4	151	58	9	3	—	—	—	—	—	—	225	1.360	−2.180	−2.547	.856
2*r*	2	65	154	96	28	7	1	—	—	—	—	353	2.306	−1.234	−1 547	.798
3*r*	—	14	88	173	128	28	6	—	—	—	—	437	3.197	−0 343	−0 547	627
4*r*	—	5	27	119	153	77	26	3	1	—	—	411	3.888	+0.348	+0.453	.768
5*r*	—	1	7	24	92	101	52	11	9	—	—	297	4.784	+1.244	+1.453	.856
6*r*	—	—	—	8	16	58	48	16	7	0	2	155	5.510	+1.970	+2.453	.803
7*r*	—	—	—	1	8	20	18	17	9	5	—	78	6.141	+2.601	+3.453	.753
8*r*	—	—	—	—	1	3	5	3	2	2	—	16	6.500	+2.960	+4.453	.665
9*r*	—	—	—	—	—	1	3	3	2	2	1	12	7.333	+3.793	+5.453	.696
10*r*	—	—	—	—	—	—	—	—	—	1	—	1	9.000	+5.460	+6.453	.846
No. of Indivs. Left Leg.	14	241	336	430	429	295	159	53	30	10	3	2,000		Mean,		.772

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In this table the first column names the subjects, of which there are as many as there are numbers of glands, viz. 0 to 10. In the succeeding columns on a single line is exhibited the distribution of the number of glands on the corresponding left legs. The column headed "Means of Lefts" gives the average number of glands on the left legs of the individuals which make up the corresponding subject. The column headed "Deviation of Rel. (d_r)" gives the deviations of the corresponding "Means of Lefts" from the mean number of left male glands. The column "Dev. of Subject (d_s)" gives the deviation of the subjects from their mean number. The last column is the quotient of d_r divided by d_s. This gives r, r', r'', etc. The last number in the column is the mean of all these values of r. This number multiplied by $\frac{A_s}{A_r}$ will give R, the value sought. But $\frac{A_s}{A_r}\left(=\frac{1.41083}{1.41089}\right)$ is nearly unity, so that the Index of Correlation of the number of glands of the right and left legs is .772. Galton has shown that the same ratio holds true when relative and subject are interchanged.

By a process similar to the preceding we have found that the ratio of correlation of right and left legs in the female is .783. This ratio is so similar to that obtained for males as to justify the conclusion that *the index of correlation in variability of the leg glands is approximately equal in the two sexes, and is about* .777.

The conclusions from this study may now be summed up. We have in the leg glands of swine a serially arranged system of organs developing, for the most part, in one line, starting at one point, and extending out a variable distance. On such a system of organs we investigate quantitatively the question, How closely similar are the morphogenic processes which determine the resemblance of these glands on the opposite sides of the body and in the two sexes? First of all, the *average* number of glands is tolerably but not strikingly close on the two fore legs and in the two sexes. The glands are nearly 1% more abundant in the male than in the female. When we come to study their variability we find that the variants are distributed in accordance with the probability curve, very nearly. (See diagram.) A curious lack of symmetry results from the fact that, since the mean lies at 3.5, variation is limited to 3.5 in one direction, but is unlimited (reaches as a matter of fact to 6.5) in the other. The degree of variability in the right and left legs is, especially in the case of the male, strikingly similar, being 1.41089 and 1.41083 in the two cases respectively, the difference being within the

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errors of the method. The males are about 2.5% more variable than the females. The glands are 0.8% more variable on the left side than on the right. The relative variability of the same leg in the different sexes is about 1.6% greater than that of the two legs in the same sex. The degree of correlation in the variability of the right and left legs is about .777.

CAMBRIDGE, MASS., July 25, 1896.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF THE CASE SCHOOL OF APPLIED SCIENCE.

INVESTIGATIONS ON AMERICAN PETROLEUM.

By Charles F. Mabery.

XXVI. — *ON THE BUTANES AND OCTANES IN AMERICAN PETROLEUM.*

By Charles F. Mabery and Edward J. Hudson.

Aid in the work described in this Paper was given by the Academy from the C. M. Warren Fund for Chemical Research.

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XXVI. — ON THE BUTANES AND OCTANES IN AMERICAN PETROLEUM.*

By Charles F. Mabery and Edward J. Hudson.

Presented October 14, 1896.

As one of us (C. F. M.) has shown † the form of the butanes and octanes in American petroleum is not so well understood as other constituents of the series C_nH_{2n+2}. Concerning the butanes, except that an analysis of a gas condensed at 0° by Ronalds gave the composition required for butane, very little has been published beyond the fact that distillates have been collected at 0° and at 8°–9°. It, therefore, seemed advisable to devote some time to the separation of the butanes for the purpose of ascertaining with greater precision what hydrocarbons with these boiling points are actually contained in petroleum.

The Butanes.

The early investigations of Pelouze and Cahours ‡ indicated the presence of butane in their most volatile distillates. A portion collected between 5° and 10° gave with chlorine a "chlorbutyl," boiling point 65°–70°. In a higher distillate, whose boiling point was not given, amyl hydride was suspected by the formation of a "chloramyl" boiling at 98°–103°, but this hydrocarbon was not further identified. In the first analysis of the gas from Pennsylvania petroleum, Ronalds § condensed an oil at 0°–1°, specific gravity 0.6000 at 0°, that gave the composition

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* For efficient aid in the work of this paper, I should acknowledge my obligations to Mr. W. H. Whitfield, who selected portions of the work on the butanes as the subject of a thesis for the degree of Bachelor of Science, and to my assistants, Messrs. C. A. Soch and E. Davidson. — C. F. M.

† Proc. Amer. Acad., XXXI. 23.

‡ Compt. Rend. 1862, p. 1241.

§ London Chem. Soc., 1865, p. 54.

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required for butane. Ronalds also collected an oil between 6° and 8°, specific gravity 0.6004, vapor density 2.178, which he regarded as a mixture of butane with higher constituents. As will be shown in this paper, nothing further has been done toward verifying the pentane from which the pentyl chloride of Pelouze and Cahours was obtained, although it was really derived from the pentane boiling at 30°, as we have ascertained after many trials.

Probably on account of difficulty in procuring an adequate supply of material, Warren * gave less attention to the butanes than to the higher constituents. He collected a distillate at 0°, which, on the basis of Ronald's determination, he assumed was a butane. After repeated and careful distillation through his regulated condenser, Warren also separated a liquid, boiling point 8°–9°. Although nothing further was done towards determining its composition, Warren believed this body "to have been sufficiently purified to justify the conclusion supported by analogy that there is a constituent boiling at about 8°–9°." Since no other attempts have been made to identify the butanes, further study of these bodies was evidently necessary.

In returning to this subject, we assumed at first that it would only be necessary to enforce the results already obtained, which seemed to be supported by our first determinations.† But as the work progressed, it soon became evident that this assumption would not be justified. Taking advantage of the extremely cold weather in January, 1895, through the kindness of Messrs. Schofield, Shirmer, and Teagle, we procured 45 litres of a second distillate of the naphtha from Pennsylvania and Ohio petroleum, the most volatile portion that could be condensed with the atmospheric temperature below 0° F. Since the naphthas from Pennsylvania and Ohio petroleum are re-distilled together, it is difficult to procure this portion from either crude oil, unless, indeed, a run of the crude oil were made in the refinery with this object in view. But this did not seem necessary, since there can be little doubt that the constituents of the most volatile portion of Ohio and Pennsylvania petroleums are identical. During the continued cold weather of January, February, and March of the same year, distillation of this product was continued through a Warren condenser, filled with a freezing mixture, and the temperature of the distillates was kept very low to avoid loss so far as possible. In this manner a long series of distillations was carried on with small loss, aside from transference, except of the most volatile distillates. In these volatile

* Proc. Amer. Acad., XXVII. 56. † Ibid., XXXI. 23.

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portions, —20° to —10°, the distillation proceeded from the heat of the surrounding atmosphere, and it was regulated by cooling the still. The results obtained in the study of these distillates were so unexpected, the entire process of distillation was repeated several times during the colder months of the present year until in all 250 litres of 88° and 92° gasoline have been distilled, the portions below 12°, twenty times. The interesting results in the distillations of the present year, especially in excluding a butane at 8°–9°, are due to the patience and care of Mr. Whitfield.

In studying the derivatives of these hydrocarbons, the chlorine substitution products were first formed by bringing together chlorine and the vapor of the hydrocarbon. The method we employed differed somewhat in details from the method of Schorlemmer.* In the reaction between chlorine and the hydrocarbon, the intensity of light must be carefully regulated. In direct sunlight so much heat is developed that a flame appears with the separation of carbon. In a cloudy day the action proceeds slowly, and with less light it is suspended. We obtained the most satisfactory results both as regards the progress of the reaction and the yield of the monochlor derivative in clear sunshine with a sheet of newspaper interposed. In all our distillates the action of chlorine has proceeded with great readiness in the cold. The distillates collected below 0° were well cooled by means of a freezing mixture. The condensation of the chlorinated product was more complete in a capacious bottle. — a two-litre bottle for 100–200 c.c. of the oil, with the delivery tube extending half way from the top of the bottle to the surface of the liquid. The heavier chlorine comes into intimate contact with the vapor of the oil, and the product condenses for the most part on the side of the bottle. Some of it unavoidably escapes with the hydrochloric acid, and it may be condensed in part by placing in front another bottle well cooled, or still better by passing the escaping gas through water. We have not found it essential to separate by distillation the chlorinated product from the hydrocarbon until the action was finished. If it be stopped with a small amount of the hydrocarbon unchanged, which may easily be determined by experience, the product is nearly all the monochlor-compound. The use of iodine suggested by Schorlemmer has not seemed essential, at least in the formation of the butane derivatives, since, without it, there is no difficulty in obtaining 80 per cent of the monochlor-compound, the remainder consisting for the most part of unchanged hydrocarbon, nor in our experience

* Philosophical Transactions, CLXII. 111 (1872).

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is the yield increased by the use of iodine. In the separation by fractional distillation of the products of the chlorination, our experience is not in accordance with that of Schorlemmer, who stated that neither the chlorides nor the acetates could be separated by distillation. With long continued distillation, as our results will show, the crude product of the chlorination may be separated into its constituents sufficiently to yield constant boiling points and satisfactory analytical data.

Since Beilstein* found that isobutane boils at $-17°.5$, it seemed reasonable that it should be contained in our product $-10°$, especially since a considerable portion of this distillate condensed below $-15°$. In submitting 200 grams of this distillate in several portions to the action of chlorine with all possible precautions, a considerable portion of the chlorine product was lost, probably because it consisted to a large extent of the more volatile chlorine derivatives of propane. Although much of the unchanged hydrocarbon must have escaped with the gaseous hydrochloric acid, 100 grams remained after the chlorination, which was washed, dried, and distilled. Prolonged distillation, however, failed to collect any considerable portion within sufficiently close limits to indicate the presence in appreciable quantity of an individual hydrocarbon. A small quantity, perhaps 5 grams, collected between 65° and 70°, doubtless isobutane, which had not been completely removed into the higher fractions at 0°. But the product distributed itself along in degree fractions from 30° to 150° at no point in quantities larger than half a gram or one gram.

Between $-10°$ and $-2°$ much smaller quantities of the hydrocarbon distillates were obtained, but within the limits $-2°$ and 2°, 300 grams came together, and the distillate $-0°$–$1°$ gave, as its specific gravity at 0°, 0.6029, and at $-12°$, 0.6141. Ronalds found as its specific gravity 0.6000. A vapor density determination gave the following value: —

0.0945 gram of the oil gave 73.6 c.c. of vapor at 5°, and under 370.4 mm. of mercury.

Calculated for C_4H_{10}.	Found.
2.01	2.07

In quantities of 100 grams each, the fractions $-2°$ to 2° were converted into the chlorine derivatives. The chlorination of such a quantity is of necessity somewhat tedious; it requires continuous operation during ten or twelve days, and it cannot be hastened, since too rapid absorption generates heat, and rapid escape of hydrochloric acid carries off the pro-

* Ann. Chem. Pharm., CXLIV. 10.

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duct. With care we were able to complete the absortion of sufficient chlorine without any considerable loss. In subjecting the chlorine product to fractional separation, after the fifth distillation it began to collect between 65° and 70°, and after the twentieth, 80 per cent collected at 68°–69°. Of the remainder, 40 grams below 60° proved to consist mainly of unchanged hydrocarbon with sufficient chlorine product to raise the boiling point. Distillation of the higher portions was continued in 1° fractions to 160°, beyond which very little remained. To prevent a slight decomposition above 150°, at first distillation was conducted *in vacuo;* but the boiling points soon fell below the point of decomposition. In this entire series of 1° distillates, only at 120°–121° did any appreciable quantity collect, and here only to the extent of 2 to 3 grams. The portions collected at other points were doubtless mixtures in very small amounts of higher chlorine products. The liquid 68°–69° was shown by analysis and vapor density to have the composition required for monochlorbutane.

I. 0.1288 gram of the oil gave 0.2440 gram CO_2, and 0.1166 gram H_2O.
II. 0.2025 gram of the oil gave 0.3845 gram CO_2, and 0.1778 gram H_2O.
III. 0.2537 gram of the oil gave by the Carius method 0.3950 gram AgCl.
IV. 0.2645 gram of the oil gave 0.4078 gram AgCl.

	Calculated for C_4H_9Cl.	Found.			
		I.	II.	III.	IV.
C	51.89	51.65	51.77		
H	9.73	10.06	9.76		
Cl	38.38			38.50	38.13

In a determination of its specific gravity at 24°, this butyl chloride gave 0.8690; at 27°.8, another determination gave 0.8648. The latter value agrees closely with that of Perin and Puchot,* who found at 27°.8, 0.8650.

In determining its vapor density by the method of Hofmann, 0.0975 gram of the oil gave 65 c.c. of vapor at 100° and under a tension of 36.44 mm.

Calculated for C_4H_9Cl.	Found.
3.20	3.30

In further evidence of its identity, this butyl chloride was converted into the acetate by heating it twenty-four hours to 140° with fused

* Ann. Chem. and Pharm., CXXXVI. 1276.

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potassic acetate and glacial acetic acid, according to the method of Schorlemmer. Upon diluting the contents of the tube, the oil which separated distilled for the most part at 116°–117°, corresponding to the boiling point of isobutyl acetate, 116°.5. The acetate was converted into the alcohol by heating with alcoholic potassic hydrate, and its boiling point, 107°–108°, showed it to be isobutyl alcohol, boiling point 108°–109°. Upon analysis the alcohol gave the required percentages of carbon and hydrogen: —

0.1737 gram of the substance gave 0.4090 gram CO_2, and 0.2113 gram H_2O.

	Calculated for C_4H_9OH.	Found.
C	64.86	64.22
H	13.51	13.52

Isobutyl sulphide was also prepared by boiling the chloride with an alcoholic solution of potassic sulphide. It gave the required percentage of sulphur: —

0.1640 gram of the oil gave by the method of Carius 0.2631 gram $BaSO_4$.

	Calculated for $(C_4H_9)_2S$.	Found.
S	21.92	22.03

As already explained, prolonged fractional distillation failed to show the presence of any other chlorine derivative of this hydrocarbon except one that distilled tolerably constant at 121°–122°. The quantity of this product was too limited to admit of complete purification; while the analyses showed that it still contained monochlorbutane, the results are sufficiently close to establish the presence of a dichlorbutane. Since no dichlorbutane with this boiling point has hitherto been found, it is to be regretted that our supply of material was so limited. But on account of the vast amount of labor that would be necessary to obtain an adequate quantity, it has not seemed of sufficient importance in the pressure of other portions of this work.

This substance gave the following results on analysis: —

I. 0.1390 gram of the oil gave by combustion with plumbic chromate 0.1960 gram CO_2, and 0.1887 gram H_2O.

II. 0.2360 gram of the oil gave 0.5245 gram AgCl.

	Calculated for $C_2H_4Cl_2$.	Found. I.	Found. II.
C	37.79	38.46	
H	6.30	7.08	
Cl	55.91		54.94

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The quantity of this product was insufficient for a determination of its specific gravity. The following value was obtained as its vapor density : —

0.1655 gram of the oil gave 87.2 c.c. of vapor at 182°, under a tension of 447 mm.

Calculated for $C_4H_8Cl_2$.	Found.
4.39	4.16

Our first attempts towards separating the butanes were made before the necessity of long continued distillation was fully appreciated. Not until after several trials was it observed to what an extent a small proportion of isobutane depressed the boiling point of pentane. In the earlier work, after six or eight distillations the product was assumed to be sufficiently pure for chlorination. A study of the chlorine derivatives showed beyond question that the hydrocarbon was pentane. We were still further misled by the boiling point of the pentyl chloride, 96°, which did not correspond to that of any hitherto published. Referring to our former notes on the vapor density of the distillate 8°–9°, we found the following determinations : —

I. 0.0717 gram of the oil gave 45.5 c.c. of vapor at 16°, under a tension of 48.1 cm. of mercury.

II. 0.0849 gram of the oil gave 46.8 c.c. of vapor at 18°.5, under a tension of 47.75 cm. of mercury.

III. 0.0999 gram of the oil gave 51.5 c.c. of vapor at 18°.5, under a tension of 51.75 cm. of mercury.

IV. 0.0751 gram of the oil gave 43.5 c.c. of vapor at 18°.5, under a tension of 45.76 cm. of mercury.

Calculated for		Found.			
C_4H_{10}.	C^5H_{12}.	I.	II.	III.	IV.
2.01	2.49	2.04	2.38	2.35	2.36

It will be seen that determination I. corresponds closely to the composition of butane, and determinations II., III., and IV. to that of pentane. When these determinations were made, we expected results that would substantiate what had previously been done on the butanes, and therefore accepted only the first result, which was the last one obtained, as supporting this view. But in the light of further knowledge of these bodies, the determinations thought to be erroneous correspond more nearly to pentane, although showing the influence of the small quantity of isobutane. The first result was published in a former paper,* when

* These Proceedings, XXXI. 24.

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it was assumed that we had in hand the butane which Warren had previously separated. Suspecting, therefore, the purity of our hydrocarbon distillate 8°–9°, in resuming this work the distillation was conducted with a sufficient quantity of material, and carried far enough to separate completely all fractions between 5° and 20°. In the fraction 8°–9°, after the tenth distillation, two vapor density determinations gave, (I.) 2.17, (II.) 2.17. In a distillate 6°–8°, Ronalds * obtained as its vapor density 2.178, evidently indicating as our values do a mixture of butane and pentane.

But continuing this distillation in single degree fractions, scarcely anything remained within these limits after the twentieth distillation. Having obtained the same result in several quantities of forty-five litres each, collected at different dates, it became evident that neither Pennsylvania nor Ohio petroleum contains a single body with a boiling point between these limits. Furthermore, we have not been able to detect normal butane in any of these volatile distillates. There is not the least difficulty in separating chlorine derivatives of these hydrocarbons by fractional distillation. All the chlorine products we have prepared have collected readily within the limits of temperature of their characteristic boiling points. But in no instance in the chlorination of hydrocarbon distillates collected between —10° and 20° has a distillate collected at 77°–78°, the boiling point of normal butyl chloride. Having excluded a constituent of Pennsylvania and Ohio petroleum within the limits mentioned above, and having observed that certain properties of isopentane derivatives are not in all respects identical with those previously published, it seemed to us of sufficient interest to devote some attention to the derivatives of this hydrocarbon. We therefore collected several hundred grams of a distillate at 29°–30°, and exposed the oil to the action of chlorine in several separate quantities until about 200 c.c. of the substitution product was obtained. In generating such large quantities of chlorine, without discomfort from leaks, we have found the large Berlin porcelain stills extremely convenient. The chlorinated product was washed, dried, and carried through a long course of distillations, until after the eighteenth distillation it collected to the extent of 85 per cent between 95° and 96°, under a constant tension of 730 mm., which for convenience was selected for all these distillations. In a large series of distillations a constant tension is simply and very conveniently obtained by means of the tension regulator elsewhere described,† with the stopcock manipulated by a lever movable

* These Proceedings, XXXI. 10. † Journ. Ch. Soc., 1865, p. 54.

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on a horizontal support. By a suitable adjustment of side tubes, stopcocks and adapters, any number of distillation flasks may be introduced into the train, and regulated by the single stopcock. As many as fifteen distillations collecting in single degree fractions have been in simultaneous operation with no interruption incident to changes of flasks or collection of distillates. It is quite impossible, in Cleveland, to carry on a course of distillations extending through several weeks without some form of tension regulator, on account of sudden and extreme changes in the barometric pressure, ocasionally equivalent to 25 mm. within a few hours.

Under 760 mm. and with the thermometer wholly in the vapor, chlorpentane distilled completely between 96° and 97°, for the most part at 96°.5. From a distillate below 30°, Pelouze and Cahours obtained a butylchloride, as already mentioned, which boiled at 98°–103°.

The purity of our product was shown by analysis : —

I. 0.1205 gram of the oil gave 0.2479 gram CO_2, and 0.1139 gram H_2O.

II. 0.2166 gram of the oil gave 0.2952 gram AgCl.

III. 0.2942 gram of the oil gave 0.4031 gram AgCl.

	Calculated for $C_5H_{11}Cl$.	Found. I.	II.	III.
C	56.33	56.13		
H	10.33	10.51		
Cl	33.33		33.69	33.88

A determination of the specific gravity of this chlorpentane at 20° gave 0.8750. Its vapor density by the Hofmann method was found to have the following value : —

0.1291 gram of the oil gave 72.6 c.c. of vapor at 100°, and under a tension of 384 mm.

Calculated for $C_5H_{11}Cl$.	Found.
3.68	3.72

In forming isopentyl acetate, the purified chloride was heated 48 hours to 150°–160° with potassic acetate and glacial acetic acid. When washed, dried, and well fractioned, a small quantity collected at 134°–135° (760 mm.), which is somewhat lower than the boiling point of isoamyl acetate, 138°.6. The amount of our material was not sufficient to raise its boiling point, but it gave the required percentages of carbon and hydrogen.

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0.1556 gram of the oil gave 0.3651 gram CO_2, and 0.1514 gram H_2O.

	Calculated for $C_5H_{11}C_2H_3O_2$.	Found.
C	64.60	64.00
H	10.80	10.81

When heated during several hours with alcoholic potash, the acetate was converted into the alcohol which was separated from the solution with salt. On account of the small quantity of the alcohol obtained, its boiling point could not be raised above 117°–120° (boiling point of inactive amyl alcohol 131°), although its composition corresponded to that of amyl alcohol.

0.1866 gram of the oil gave 0.4620 gram CO_2, and 0.2293 gram H_2O.
0.1854 gram of the oil gave 0.4610 gram CO_2, and 0.2315 gram H_2O.

	Calculated for $C_5H_{11}OH$.	Found. I.	Found. II.
C	68.18	67.51	67.81
H	13.63	13.66	13.88

At higher temperatures to 150°, the crude chlorine product could be distilled without decomposition. Above this point the residue was distilled *in vacuo*, which reduced the boiling point to such an extent that further distillation could be carried on under atmospheric pressure, leaving only a very small residue above 150°, probably of substitution products containing a larger number of chlorine atoms.

At no point between 96° and 160° could a distillate be held constant, except at 144°–145°. Here 5 grams collected after the fifteenth distillation that distilled at 144°–146°, mostly at 145°, under 760 mm. and with the mercury column wholly in the vapor. This oil proved on analysis to have the composition required for dichlorpentane.

I. 0.1309 gram of the oil gave 0.2055 gram CO_2, and 0.0888 gram H_2O.
II. 0.1976 gram of the oil gave 0.3993 gram AgCl.

	Calculated for $C_5H_{10}Cl_2$.	Found. I.	Found. II.
C	42.56	42.84	
H	7.09	7.54	
Cl	50.36		49.96

A determination of the vapor density of this body gave a value corresponding to dichlorpentane.

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0.1680 gram of the oil gave 80.6 c.c. of vapor at 182°, and under a tension of 426 mm.

Calculated for $C_5H_{10}Cl_2$.	Found.
4.88	4.78

The boiling point of this dichlorpentane is the same as that of amylene chloride, 145°, described by Bauer.* It is to be regretted that the quantity of our product was so limited; but on account of the great amount of labor involved in its preparation, it did not seem advisable to attempt the preparation of a larger amount.

These results indicate that petroleum contains but one butane, and that is isobutane, which collects at 0°. That this body is not normal butane is shown by the boiling point, 67°–68°, of the monochlor derivative, the boiling point, 116°, of the acetate, that of the alcohol, 108°–109°, and that of the sulphide, 172°. It has hitherto been assumed that the butane in petroleum is the normal hydrocarbon, because the butane prepared by Frankland from ethyl iodide and zinc boils at 0°. But isobutane prepared by Butlerow from tertiary butyl alcohol should boil at —17.°5. The differences between the properties of butane and isobutane are sufficiently marked to permit, without difficulty, of distinguishing between the isomeric forms.

Normal butyl chloride boils at 77°.6, and the alcohol at 117°. Since our series of derivatives from petroleum butane was prepared several times with the same results, and never with the formation of compounds with boiling points corresponding to normal butane, there can be no question that normal butane is not contained in Pennsylvania nor in Ohio petroleum. The serious question concerns the boiling point of isobutane which we found in petroleum. As has been fully explained, our 0° fractions were separated as many as four different times from the lightest gasoline we could procure from the refinery. While we never failed to collect distillates below —10°, they were much smaller in quantity than those in the vicinity of 0°. It is, therefore, certain that the butane we had in hand was isobutane, and it seems equally certain that this hydrocarbon collected at 0° and not at —17°.

The Octanes in Ohio Petroleum.

It has already been pointed out by one of us (C. F. M., *loc. cit.*) that the published accounts of the octanes in petroleum are not fully

* Zeit. für Chem., 1866, p. 380.

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concordant. Pelouze and Cahours first announced in their series of hydrocarbons an octane, boiling point 116°–118°, and a little later Schorlemmer* found a body in coal tar distilling at 119°–122°, and another at 124°, both with the composition required for octane. Possibly led to believe by the results of Beilstein and Kurbatoff that the distillate 119°.5–122° is hexahydroisoxylol, in his later summation of the octanes known Schorlemmer seems to repudiate the one boiling at 119°–122°, which he had previously described. Warren recognized two octanes, one boiling at 119°.5, and another boiling at 127°.6. These bodies were identified alone by vapor density determinations and boiling points; no analyses were given. In the separation of the hydrocarbons resulting from the distillation under pressure of menhaden oil, Engler discovered the octane, diisobutyl, boiling point 109°. In support of the work of Pelouze and Cahours, Lemoine† submitted American ligroine to *four* fractional distillations, collecting distillates within limits of *five* degrees, and separated an octane, boiling point 121° at 779 mm. In our experience, the hydrocarbons in petroleum with boiling points not far removed can only be separated by the use of the best possible means for fractional separation, in a long course of distillations. The separation of the octanes, for example, requires a refinery distillate boiling between 120° and 170°, and it is not until the twentieth distillation that the octanes begin to accumulate with any degree of purity. In all our experiments after the fifth distillation, the octanes are still contained for the most part in the portions above 125°, and they are separated very slowly into their respective fractions. In undertaking further study of the octanes in Ohio petroleum, we procured from the refinery of Messrs. Schofield, Shirmer, and Teagle 72 litres of a burning oil distillate that distilled in our hands, within the limits of ten degrees, in the following proportions: —

	−75°	75°–100°	100°–110°	110°–120°	120°–130°	130°–140°	140°–150°	150°–160°	+160°
Litres	10	12	10	8	8	8	5	5	5

The sulphur compounds were precipitated from these fractions by means of alcoholic mercuric chloride, the oils washed and dried, and the distillation continued within limits of 5°, 2°, and finally within 1°, under a constant tension of 730 mm. In further explanation of what was said above concerning the slow separation of these constituents, the following record of the tenth distillation is given; when it is borne in mind that

* Jour. Chem. Soc., XV. 419. † Bull. Soc. Chem., XLI. 161.

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these weights are from 65 litres, the small amounts of the constituents will be appreciated: —

	115°–116°	116°–117°	117°–118°	118°–119°	119°–120°	120°–121°	121°–122°
Grams	50	60	80	100	145	130	160

	122°–123°	123°–124°	124°–125°	125°–126°	126°–127°	127°–128°	128°–129°
Grams	120	170	160	150	120	90	40

If the distillation had been stopped at this point, since on account of the diminished tension the true boiling points should be at least one degree higher than those given, it might be inferred that one of the principal constituents was a hydrocarbon boiling at 126°–127°.

No doubt this inference would be supported by the vapor density of this product, but further distillation showed its fallacy. At the end of the thirty-third distillation, 190 grams collected at 118°.5–119°.5, which distilled between 119°.5 and 120°, for the most part at 119°.5, under 760 mm. with the mercury column wholly in the vapor. Its specific gravity at 20° was found to be 0.7243. This liquid was assumed to have the same composition as the octane whose identity was shown by analysis and a vapor density determination.*

The vapor density of this product was found to support the same composition:—

0.1287 gram of the oil gave 75 c.c. of vapor at 182°, and under a tension of 429 mm.

Calculated for C_8H_{18}.	Found.
3.95	3.91

The specific gravity of the crude distillate was found to be 0.7256. The presence of this hydrocarbon is still further assured by the prolonged distillation. Our boiling point is practically the same as that of Warren, although his product from Pennsylvania petroleum must have been contaminated to some extent by hexahydroisoxylol, which was not shown to be present in Pennsylvania oil until long after the work of Warren was completed. Our boiling point was taken in a portion of the Ohio oil which had been subjected to prolonged treatment for the removal of hexahydroisoxylol. The specific gravity of this distillate purified by fuming sulphuric acid with the aid of heat was 0.7230. Another portion purified with a mixture of nitric and sulphuric acids gave as its specific gravity 0.7190. In the oil with

* Mabery, *loc. cit.*

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the same boiling point separated from coal tar, Schorlemmer found the specific gravity 0.7190 at 17°.5. In our product purified with fuming sulphuric acid, the required percentages of carbon and hydrogen were obtained.

0.1475 gram of the oil gave 0.4562 gram CO_2, and 0.2073 gram H_2O.

	Required for C_8H_{18}.	Found.
C	84.22	84.35
H	15.80	15.62

In the formation of chlorine derivatives from this octane, the same method was employed without cooling as in the case of the more volatile distillates. It was ascertained that the best yield of monochloroctane was given when the quantity of chlorine absorbed was 50 per cent in excess of the amount theoretically required to form the monochlor derivative. Even with this excess, still a small amount of the hydrocarbon remained unchanged. Since it was found that the chlorinated compound could not be distilled under atmospheric pressure without serious decomposition, after washing and drying it was fractioned *in vacuo* under a tension of 50 mm., within limits of 10°, 5°, 2°, and finally for some time within 1°. Under 50 mm. fractions collected at all points between 65° and 150°, but a larger quantity at 83°–84°, which under atmospheric pressure distilled at 164°–166°. The composition of this substance was determined by analysis: —

I. 0.1479 gram of the oil gave 0.3523 gram CO_2, and 0.1537 gram H_2O.
II. 0.1961 gram of the oil gave 0.1888 gram AgCl.
III. 0.2483 gram of the oil gave 0.2408 gram AgCl.

	Calculated for $C_8H_{17}Cl$.	Found. I.	II.	III.
C	64.65	64.95		
H	11.45	11.54		
Cl	23.90		23.81	23.97

A determination of vapor density gave a value required for monochloroctane: —

0.1682 gram of the oil gave 78 c.c. of vapor at 182°, and under a tension of 400 mm.

Required for $C_8H_{17}Cl$.	Found.
5.14	5.28

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The monochloroctane obtained by Pelouze and Cahours,* and by Schorlemmer,† from petroleum octane, boiling point 168°–172°, was evidently a mixture of the two chloroctanes from the hydrocarbons 119°.5 and 124°. It could not be otherwise, on account of the imperfect separation of the hydrocarbons. In our experience, nothing less than thirty distillations is sufficient for the separation of these bodies with any degree of purity.

In comparing the results in this paper with those of others, it should be borne in mind that our products were separated from Trenton limestone petroleum, which was unknown at the time of the earlier study of Pennsylvania oil. But there can be little doubt that these portions of Pennsylvania and Ohio oils are identical so far as the principal constituents are concerned. That this is true of constituents with boiling points above 150° will be shown in another paper.

In many instances, even after the most careful purification, the specific gravity of the petroleum hydrocarbons is somewhat higher than that of the same hydrocarbons synthetically prepared. Schorlemmer ‡ thought this was due to fine differences of isomerism. But this was before the discovery of naphtenes in petroleum. It now seems very probable that the higher specific gravity is due to the difficulty in removing the last trace of these bodies, especially since a small excess of carbon and a slight deficiency in hydrogen for the formula C_nH_{2n+2} accompanies the higher specific gravity. A notable quality of the naphtenes is their inertness toward reagents, which is doubtless greatly increased by large dilution in the principal petroleum hydrocarbons.

In Russian petroleum, Markownikoff and Putochin § discovered isoctonaphtene, boiling point 122°.5. In looking for this hydrocarbon in Ohio petroleum the fractions 120°–124° were carefully distilled many times, until so little remained within these limits no individual constituent could be present in any appreciable quantity, or in such quantity that it could be collected by fractional distillation and identified. The octane found by Lemoine at 121° is, therefore, also excluded.

The octane, boiling point 125°.46, separated by Schorlemmer, was assumed to be identical with normal octane formed from normal butyl iodide by the action of sodium. Warren found a somewhat higher boiling point in the octane from Pennsylvania petroleum. This body

* Jahr. 1863, p. 528.

† Ann. Chem. Pharm., CXXV. 112.

‡ Phil. Trans., CLXXI. 451 (1880).

§ Ber. der deutsch. chem. Gesellsch., 1885, p. 1860.

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distilled between 126°.8 and 129°.1, or in the mean at 127°.6; its composition was based upon a determination of its vapor density, but it was not supported by analysis. The observations of Warren were apparently confirmed by similar distillates separated from Ohio and Canadian petroleum.* Distillates collected at 126°–127° from these oils after the eleventh fraction gave values in vapor density determinations corresponding to that of octane. But evidently such determinations, unsupported by other data, are less reliable, especially in products not far removed in boiling points from other isomers. Although our former results apparently confirmed the presence of an octane at 126°–127°, those values were accepted as provisional, to be supported or modified by more prolonged distillations which have now been made.

Under a constant tension of 730 mm., forty-two distillations were made between 121° and 130° through Hempel bead columns. Of the last distillates scarcely any remained at 126°–127°, or between this point and 130°, and very little at 125°–126°. The greater portion, 200 grams, collected at 124°–125°, normal conditions. There is, therefore, in Ohio petroleum, no octane with a boiling point higher than 125°. After purification with a mixture of nitric and sulphuric acids and sodium, the distillate 124°–125° was shown by analysis to have the composition for octane.

0.1471 gram of the oil gave 0.4544 gram CO_2, and 0.2077 gram H_2O.

	Calculated for C_8H_{18}.	Found.
C	84.22	84.26
H	15.79	15.70

After thorough treatment with fuming sulphuric acid, this octane gave 0.7183 as its specific gravity. Another portion, carefully purified with a mixture of nitric and sulphuric acids gave 0.7134. The specific gravity of the synthetic hydrocarbon was given by Thorpe as 0.7188. The crude distillate, with no purification, gave as its specific gravity 0.7243. Its vapor density was found by the method of Hofmann.

0.1578 gram of the oil gave 84.4 c.c. of vapor at 182°, and under a tension of 462 mm.

Calculated for C_8H_{18}.	Found.
3.95	3.96

In the formation of monochloroctane from this distillate, the hydrocarbon was exposed to the action of chlorine in the cold until the

* Mabery, Proc. Amer. Acad., XXXI. 32, 57.

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increase in weight was fifty per cent in excess of the quantity theoretically required to form monochloroctane. The product, containing a small amount of the hydrocarbon still unchanged, was washed, dried, and submitted to fractional distillation *in vacuo* under 50 mm., since it was found that it could not be distilled under atmospheric pressure without decomposition. A considerable portion collected at 89°–91°, that distilled under atmospheric pressure, normal conditions, at 173°–174°. Schorlemmer stated that chlorine converts normal octane into a mixture of primary octyl chloride, boiling point 179°–180°, and secondary octyl chloride boiling at 175°. None of our product collected at the point corresponding to the normal chloride, although the quantity was not sufficient to determine the boiling point with absolute precision, and not sufficient to form other compounds. Pelouze and Cahours * gave 168°–172° as the boiling point of the chloride which they formed from petroleum octane, but their hydrocarbon was evidently not fully purified.

This substance gave upon analysis percentages of carbon, hydrogen, and chlorine required for chloroctane : —

I. 0.1222 gram of the oil gave 0.2880 gram CO_2, and 0.1264 gram H_2O.

II. 0.1821 gram of the oil gave 0.1792 gram AgCl.

III. 0.2203 gram of the oil gave 0.2200 gram AgCl.

	Calculated for $C_8H_{17}Cl$.	Found. I.	II.	III.
C	64.65	64.27		
H	11.45	11.49		
Cl	23.90		24.33	24.69

A determination of vapor density gave a value required for chloroctane : —

0.1675 of the oil gave 76 c.c. of vapor at 182°, and under a tension of 418 mm.

Calculated for $C_8H_{17}Cl$.	Found.
5.14	5.16

The small amount of distillates above 91° *in vacuo* showed the presence in minute proportions of higher chlorinated products, but it would require much larger quantities than we could conveniently procure to ascertain their composition.

* Jahr. Fittig, 1863, p. 528.

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Since Engler* discovered tetramethylbutane or diisobutyl, boiling point 108.5°, as one of the products in the distillation of fats under pressure, with the possibility that this body might be present in Ohio petroleum, we submitted the portions of this petroleum distilling between 100° and 115° to prolonged distillation within single degree limits. But after treatment with nitric acid. no distillate collected in this vicinity. Having in hand a series of fractions near 135°–136°, the boiling point of hexahydromesitylene, or mononaphtene, they were carried through a long course of distillations, and the small amount remaining within these limits was examined with the aid of fuming nitric acid and fuming sulphuric acid, but no sulphonic acid was formed, and the very small amount of nitro compound was not sufficient for a melting point.

In view of the fact that the series of petroleum hydrocarbons boiling approximately at 38°, 68°, and 98°, have received little attention since they were first discovered by Warren, I shall soon undertake an examination of these bodies, and also of petroleum nonane to which Warren assigned the boiling point 151°.

* Ber. der deutsch. chem. Gesellsch., 1889, p. 592.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF THE CASE SCHOOL OF APPLIED SCIENCE.

INVESTIGATIONS ON AMERICAN PETROLEUM.

By Charles F. Mabery.

XXVII. — *THE CONSTITUENTS OF PENNSYLVANIA, OHIO, AND CANADIAN PETROLEUM BETWEEN* 150° *AND* 220°.

By Charles F. Mabery.

Aid in the work described in this Paper was given by the Academy from the C. M. Warren Fund for Chemical Research.

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XXVII. — THE CONSTITUENTS OF PENNSYLVANIA, OHIO, AND CANADIAN PETROLEUM BETWEEN 150° AND 220°.

By Charles F. Mabery.

Presented October 14, 1896.

The conflicting statements published long ago, and still uncorrected, concerning the composition of the portions of Pennsylvania petroleum distilling above 150°, the absence of any information relating to the constituents of Ohio and Canadian petroleum, and the erroneous assumptions as to the composition of American petroleum based on the results of Markownikoff and his assistants in the Russian oil, taken together, render a study of these portions of American petroleum of extreme interest. One cannot fail to be impressed with the marked differences of opinion that have prevailed as to the composition of the portions of American petroleum with higher boiling points. Some authorities, influenced by the profound investigations of the Russian chemists on the Caucasus oil, have believed that the constituents of American oil above 150° are naphtenes, with a reservation as to whether the series C_nH_{2n} announced by Warren should be accepted as naphtenes. Others, depending on the results of Pelouze and Cahours, which form the basis of the statements in chemical literature concerning the constituents of these petroleums, have held that the series C_nH_{2n+2} does not find its last representative in nonane, boiling point 151°. Similar differences of opinion have been expressed by practical oil men, those who have witnessed the development of the petroleum industry from the beginning, concerning the composition of these oils. Some believe that Canadian and Ohio oils are essentially and fundamentally different from the Pennsylvania oil. Others hold that the chief constituents are identical, and that differences observed in refining are due to variations in the proportions of the principal constituents, and to the presence in some oils of small amounts of other bodies that are not found in all. I must admit that my earlier impressions on this subject have not been verified in the light of the results which will be presented.

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This work was undertaken with the expectation that Pennsylvania oil would prove to consist in its higher portions of a series C_nH_{2n}, and it is only after a great amount of laborious study, and a vast accumulation of analytical data, presenting unquestionable evidence that, for the hydrocarbons distilling within these limits of temperature, except those collecting at 196° and 216° from Canadian petroleum, this series must be discarded, that I accept this conclusion. Concerning the composition of Ohio and Canadian petroleum, in the beginning of this work, I had no preconceived ideas.

The separation of constituents with higher boiling points presents greater difficulties than those in the portions distilling below 150°. In the lower portions there is no danger of decompositions during distillation, both on account of greater stability of the hydrocarbons and because the unstable bodies, such as the nitrogen, oxygen, and sulphur compounds, as well as the more complex hydrocarbons, distil for the most part at higher temperatures. Then distillation in air has little if any effect on the lower constituents, while the portions distilling at higher temperatures cannot be volatilized in the presence of air without more or less decomposition. As has been shown, distillation *in vacuo* prevents changes due to inherent instability and it excludes air, but it increases very much the labor of the separations. It has been found to be especially serviceable in separating the hydrocarbons under consideration, since these bodies are contained for the most part in portions of the first distillate boiling above the limits of cracking, and are consequently contaminated by the products of decomposition when distilled in air, and the decomposition products are difficult to remove. Evidently any experiments on a laboratory scale may fail to reveal the presence of bodies that are present in proportionately minute quantities. It would be interesting, and from a commercial point of view doubtless profitable, to establish a more extended investigation involving the manipulation of at least a hundred barrels of crude oil, continuing the fractional separations of all portions until the individual hydrocarbons were as perfectly isolated as is done with smaller quantities in the laboratory. Such an investigation could only be undertaken at large expense, and a long time would be required to reach desirable results.

In undertaking this subject, the course to be followed was plain. There is but one method for the separation of these hydrocarbons, and it yields satisfactory results only after long and tedious application. Concerning the question as to whether fractional distillation can be relied on for the separation of hydrocarbons with boiling points not far removed,

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it can, I think, be stated with confidence that distillations many times repeated under constant conditions may be expected to yield products whose composition can be determined, after suitable purification, as accurately as the methods of analysis will permit. But hydrocarbons separated from petroleum in this manner, before purification, may be contaminated by other bodies whose boiling points are nearly the same. As an illustration, to ascertain whether Ohio petroleum contains a hydrocarbon boiling at 162°, a course of fractional separations under 730 mm. was repeated fifty times, forty-five times within one degree. One portion after treatment with fuming sulphuric acid had its specific gravity changed from 0.7717 to 0.7535, but it still distilled within the same limits. Another portion of the same distillate, after treatment with common concentrated sulphuric acid, gave a product with the same specific gravity and the same boiling point as the oil before treatment. The crude distillate contained a certain amount of mesitylene, boiling point 163°, sufficient, as will appear later, to affect seriously the percentages of carbon and hydrogen. In the main, the hydrocarbons described in this paper as collecting between 160° and 216° have the same boiling points as those described by Warren, except one which collected at 162°. It is peculiar that these bodies have nearly the same boiling points as the naphtenes separated by Markownikoff from the Russian oil. In previous investigations on these hydrocarbons, except those of Warren, evidently the course of distillation was not carried far enough to separate with any degree of purity the individual constituents. In the light of Warren's distillations and those here presented, it is evident that Pelouze and Cahours could not have carried their separations far enough to obtain individual products. Concerning the thoroughness of Warren's separations there can be no question. But the deficiency in his work on the hydrocarbons now under consideration was the result of the limited knowledge then prevailing concerning the general composition of petroleum. The aromatic hydrocarbons, the oxygen compounds, and the nitrogen compounds, were not then recognized, or were merely suspected as constituents of petroleum. In the purification of his distillates, the single method adopted by Warren consisted in boiling with sodium, as shown by the following statement: "I must state, however, once for all, that, unless specially mentioned, no one of the bodies operated upon had received any chemical treatment except that of boiling with sodium." * But that Warren suspected the presence in his distillates of other bodies is indicated by a quotation from

* Proc. Amer. Acad., XXVII. 66.

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one of his private papers, already mentioned in another paper: "The samples analyzed may have contained traces of more highly hydrogenized substances, and that it would be worth while to treat with $HOSO_2$, and $HONO_2$, and remove these."* It is evidently an error to consider the hydrocarbons C_nH_{2n+2}, especially the lower members, as unstable toward reagents. It has been our experience, in removing aromatic hydrocarbons from the distillate 160°–216°, that the principal constituents are not affected in the cold by a mixture of nitric and sulphuric acids, nor by fuming sulphuric acid even by warming. After purification, the boiling points do not change in a long course of distillations. No doubt the stability diminishes with a rise in boiling points, but it is sufficient to permit of purification of the members below 216°. All analyses in this paper point to the general composition C_nH_{2n+2}, except for the Canadian hydrocarbons 196° and 216°. If continued distillation or treatment with the means of purification we have adopted produces decomposition, the products should scarcely consist at least entirely of lower members of the same series.

In the comparative examination, the results of which will be described in this paper, two principal objects were kept in view, one of chief importance to determine the series of hydrocarbons which form the main body of American petroleum, and the other naturally following, to ascertain whether the composition of Pennsylvania, Ohio, and Canadian oils as regards their principal constituents is the same.

In undertaking a study of the portions of petroleum within the limits of temperature mentioned above, it was at first determined to prepare all distillates from the crude oils, and this has been done in part in the Ohio and Canadian oils. But when it was found that cracking in refining did not begin in any considerable extent below 225°, and that distillates from the refinery resembled in all respects, at least in their principal constituents, those obtained in vacuum distillation, refinery distillates were more freely employed, especially from Pennsylvania oil. But most of the results on Ohio and Canadian oils were obtained in vacuum distillates, the preparation of which was described in a former paper.† Further assurance against decomposition in the Pennsylvania product was gained by selecting during the "run" in the refinery distillation just that portion of the distillates that corresponds in gravity to the constituents desired. Experience showed that heavier portions of the crude distillate should be selected than those corresponding to the constituents

* Proc. Amer. Acad., XXXI. 31. † Ibid., XXXI. 1.

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required, since the boiling points invariably decline many degrees in subsequent distillations.

The refinery distillate employed was taken at 48°–50° Baumé, having a specific gravity 0.7892 at 20°. It was very nearly colorless and gave no odor of decomposition. Forty-five litres of this distillate was fractioned within limits of 10°, 5°, 2°, and for a long time within 1°. It gradually collected in heaps, as described by Warren, but the prolonged distillation was necessary to separate higher and lower constituents from the mixtures between.

Concerning the impression that Pennsylvania petroleum has the same composition within these limits as the Russian oil, which is based in part on the results of Warren suggesting the series C_nH_n, and in part on the erroneous statements of Höfer, that Markownikoff found the same series in Pennsylvania that he had reported in Russian oil, it may be stated once for all that this identity is clearly excluded by the great difference in specific gravity of the corresponding distillates, without reference to the differences in percentage composition. These differences in composition are indicated at the outset by the great differences in specific gravity of crude distillates at 16°, as shown by Markownikoff and Oglobine.*

	Baku.	American.
150°–200°	0.786	0.757
200°–250°	0.824	0.788
250°–320°	0.861	0.809

The same differences appear between the individual constituents : † —

Baku Naphtenes.		B.P.	Specific Gravity.
Dekanaphtene	$C_{10}H_{20}$	160°–162°	0.795 (0°)
Endekanaphtene	$C_{11}H_{22}$	180°–185°	0.8119 (0°)
Dodekanaphtene	$C_{12}H_{24}$	196°–197°	0.8055 (14°)

And the series C_nH_{2n} of Warren, purified only by distillation and boiling with sodium : ‡ —

		B.P.	Specific Gravity at 0°.
Rutylene	$C_{10}H_{20}$	174°.9	0.7703
Margarylene	$C_{11}H_{22}$	195°.8	0.7822
Laurylene	$C_{12}H_{24}$	216°.2	0.7905

* Ber. der deutsch. chem. Gesellsch., 1883, p. 1873.

† Ibid., p. 1877.

‡ Proc. Amer. Acad., XXVII. 15.

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As will be shown later, the specific gravity assigned by Warren to these constituents is very materially diminished by the removal of the aromatic hydrocarbons, and perhaps of other heavier bodies, that can only be separated by the application of more vigorous means of purification than Warren applied.

Decane, $C_{10}H_{22}$, 163°–164°.

When Pelouze and Cahours announced $C_{10}H_{22}$ as a constituent of Pennsylvania petroleum boiling at 160° ("sensiblement"), the presence in petroleum of the aromatic hydrocarbons had not been demonstrated, and since treatment with concentrated sulphuric acid and carbonate of soda was the sole means of purification, it is evident that their product must have still contained mesitylene, boiling point 163°, which, according to Engler, is contained in petroleum to the extent of 0.2 per cent. Then the specific gravity, 0.757 at 15°, assigned by them, is somewhat higher than that of this decane with mesitylene entirely removed. Warren did not observe the collection at this point of a distillate in any considerable quantity. But if, as it seems probable, Pelouze and Cahours investigated, not Pennsylvania, but Canadian petroleum, the close agreement between their specific gravity of decane at 160° with ours in Canadian petroleum is explained. In attempting to ascertain whether a hydrocarbon with this boiling point is present in Pennsylvania petroleum in any considerable amount, the distillates 150°–170° were carried through a long series of distillations, until several hundred grams collected between 158° and 162° under 730 mm., and finally more than 100 grams between 162° and 163° under 760 mm. One portion of this distillate was dried over sodium for analysis.

0.1453 gram of the oil gave 0.4560 gram CO_2, and 0.1865 gram H_2O.

	Calculated for $C_{10}H_{22}$.	Calculated for $C_{10}H_{20}$.	Found.
C	84.51	85.71	85.58
H	14.49	14.29	14.27

A determination of the specific gravity of this oil at 20° gave 0.7684. Its vapor density was determined by the Hofmann method in the vapor of aniline.

I. 0.1327 gram of the oil gave 66.8 c.c. of vapor at 182°, under a tension of 373.2 mm.

II. 0.1113 gram of the oil gave 59.5 c.c. of vapor at 182°, under a tension of 354.7 mm.

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Calculated for $C_{10}H_{22}$.	Found. I.	II.
4.92	5.21	5.16

A portion of the same distillate was treated with fuming sulphuric acid with the aid of heat, and occasional agitation. When first added, a slight rise in temperature was observed, doubtless caused by the formation of mesitylene sulphonic acid. The acid was diluted, neutralized with baric carbonate, and the filtered solution evaporated nearly to dryness. A barium salt separated in clusters of needles, sparingly soluble in cold, more so in hot water. The quantity of this salt was too small for analysis. Another portion of the same distillate, with a mixture of nitric and sulphuric acids in the cold, formed an oily layer above the acids, which became solid on standing, and after crystallization from hot alcohol the needles that separated melted at 83°–84°; melting point of dinitromesitylene, 86°. When the dinitro product was warmed with fuming nitric acid, it formed prisms sparingly soluble in alcohol, and melting at 225°; melting point of trinitromesitylene, 230°. In the treatment with acids, 16 grams of the crude distillate gave 8 grams of the purified oil, with a loss of 50 per cent. When treated with fuming sulphuric acid, 16 grams of the crude product gave 9.5 grams pure oil, with a loss of 40 per cent. Mesitylene formed, therefore, a considerable proportion of the crude distillate. The purified oil had the faint odor characteristic of the pure petroleum hydrocarbons. After the removal of the hygroscopic moisture, the oil had no effect on bright metallic sodium. It gave upon analysis values required for decane: —

0.1644 gram of the oil gave 0.5084 gram CO_2, and 0.2284 gram H_2O.

	Calculated for $C_{10}H_{22}$.	Found.
C	84.51	84.34
H	15.49	15.44

The specific gravity of the purified oil at 20° was 0.7479, a value somewhat lower, as mentioned above, than that found by Pelouze and Cahours.*

Its vapor density was determined by the Hofmann method: —

0.1221 gram of the oil gave 68.5 c.c. of vapor at 182°, and under a tension of 352.8 mm.

Calculated for $C_{10}H_{22}$.	Found.
4.92	4.91

* Ann. Chim. Phys., (4.), I. 62.

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Although the composition as shown by analysis seemed to be sufficient to demonstrate the presence of a hydrocarbon at this point, evidently analytical data alone would be insufficient, unless supported by a constant boiling point. The distillate used in the determinations described above was obtained after a long fractional separation, but without purification except the removal of sulphur compounds, until after the distillations were made. To prove beyond question the constancy in boiling point, another portion of the crude distillate after the fifteenth distillation was thoroughly agitated and warmed with fuming sulphuric acid, washed, dried, and the distillation continued fourteen times longer. About 100 grams of the oil collected so that it distilled at 163°–164°, mostly at 164°, under a tension of 760 mm., and with the mercury column all in the vapor. There seems therefore to be no reasonable doubt that Pennsylvania petroleum contains a decane with this boiling point. That this hydrocarbon is a decane is shown also by a determination of its molecular weight by the Beckmann method, which gave 142; and the formula $C_{10}H_{22}$ requires 142.

In forming the chlorine derivative of the hydrocarbon $C_{10}H_{22}$, boiling point 163°–164°, from Pennsylvania petroleum, 45 grams of the purified hydrocarbon was subjected to the action of chlorine in sunlight with a sheet of paper interposed, until it increased in weight 17 grams. The chlorine was delivered rapidly above the oil, and it was absorbed as fast as it could be added. Hydrochloric acid escaped with effervescence, and the rapidity of the reaction generated sufficient heat to maintain the temperature in the vicinity of 70°. With a slower stream of chlorine in other experiments the heat was dissipated without heating the oil, although the chlorine was as readily absorbed. Without further treatment, the chlorine product was subjected to fractional distillation *in vacuo* under tension of 80 mm. After ten distillations, approximately 6 grams collected at 125°–130°, which determinations of chlorine, carbon, and hydrogen showed to be monochlor decane: —

I. 0.2181 gram of the oil gave 0.5460 gram CO_2, and 0.2265 gram H_2O.

II. 0.2024 gram of the oil gave 0.1660 gram AgCl.

	Calculated for $C_{10}H_{21}Cl$.	Found. I.	II.
C	68.00	68.23	
H	11.90	11.55	
Cl	20.11		20.29

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The specific gravity of this chlordecane at 20° was 0.8914. To the same product, separated by Pelouze and Cahours, no specific gravity was given. The chlordecanaphtene prepared by Markownikoff and Oglobine,* from decanaphtene boiling at 160°–162°, gave as its specific gravity 0.9390 at 0°. It boiled at 205°–206° (Cor.). Chlordecane obtained by Pelouze and Cahours boiled under atmospheric pressure at 200°–204°. Our chlordecane could not be distilled under atmospheric pressure without decomposition. As nearly as its boiling point could be determined, it distilled at 197°–203°.

On account of the small quantity of the chlorine derivatives described in this paper, the specific gravity determinations may not be strictly accurate. But the errors are doubtless small, and they do not affect the value of the determinations in establishing the identity of these derivatives.

In continuing the distillation of the higher chlorinated products from 163°–164° decane, Pennsylvania petroleum, approximately 15 c.c. of an oil collected after the eighth distillation at 160°–170° that was heavier than water. Even these high distillates, which could not be heated to their boiling points without decomposition, could be distilled *in vacuo* with little if any decomposition. This product gave on analysis the values required for dichlordecane: —

I. 0.2293 gram of the oil gave 0.4829 gram CO_2, and 0.1884 gram H_2O.

II. 0.2557 gram of the oil gave 0.3420 gram AgCl.

	Calculated for $C_{10}H_{20}Cl_2$.	Found. I.	II.
C	56.87	57.42	
H	9.48	9.13	
Cl	33.65		33.09

This dichlordecane gave 1.0187 as its specific gravity at 20°.

Decane, $C_{10}H_{22}$, 173°–174°.

Above 163° (730° mm.) the distillates were small in amounts to 168°, where they began to increase, and large quantities collected within degree limits to 173°, when they again fell off to small volumes. The fraction 163°–170° was selected for examination, which included analysis of the crude distillate, analyses after purification with acids, and the

* Ann. Chim. Phys., (6.), II. 453.

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formation of the chlorine derivatives. It is interesting to note that, without purification, unpurified distillates give percentages of carbon and hydrogen that correspond to the series C_nH_{2n}, or to numbers between this series and the series C_nH_{2n+2}. The unpurified distillate 169°–170° (730 mm.) gave the following results: —

0.1521 gram of the oil gave 0.4758 gram CO_2, and 0.2018 gram H_2O.

	Calculated for $C_{10}H_{22}$.	Calculated for $C_{10}H_{20}$.	Found.
C	84.51	85.71	85.31
H	15.49	14.29	14.72

The specific gravity of this distillate at 20° was found to be 0.7502. Its vapor density, determined by the Hofmann method, gave the following value: —

0.1533 gram of the oil gave 74.6 c.c. of vapor at 182°, under a tension of 414.6 mm.

Calculated for $C_{10}H_{22}$.	Found.
4.92	4.86

Evidently no particular value can be attached to such determinations of vapor density, since, as shown by analysis, the oil is not composed of a single body. The same is true of boiling points unsupported by other values. The contaminating body frequently has the same or nearly the same boiling point as the principal constituent, and after the removal of the impurity the boiling point is not materially changed. Another portion of the crude distillate was shaken with ordinary strong sulphuric acid washed with caustic soda water, and dried with sodium.

I. 0.1476 gram of this oil gave 0.4586 gram CO_2, and 0.1980 gram H_2O.
II. 0.1674 gram of this oil gave 0.5190 gram CO_2, and 0.2263 gram H_2O.

	I.	II.
C	84.72	84.57
H	14.90	15.03

The specific gravity of this oil was 0.7486. Its vapor density was determined; 0.1454 gram of the oil gave 73 c.c. of vapor at 182°, under a tension of 410 mm.

Calculated for $C_{10}H_{22}$.	Found.
4.92	4.75

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Another portion of the crude distillate was agitated with a mixture of nitric and sulphuric acids. An oily nitro product separated above the acids, which became partially crystalline on standing. It was doubtless a nitro derivative of cymol; boiling point of metacymol 174°–176°, of paracymol 171°–172°.

The quantity of the nitro product was small, and the proportion of cymol was still further shown to be very small by treatment with fuming sulphuric acid. 185 grams of the distillates 167°–170°, after the eighteenth distillation, first by agitation in the cold, and then by warming to 125°, gave a loss in weight of only 15 grams, or about 8 per cent of the weight taken. A barium salt was formed of the sulphonic acid, but it appeared as a thick gummy mass, so uninviting that nothing further was done with it. The purification with fuming sulphuric acid was intended more especially to show whether the boiling point of the distillates would be materially affected. But the only difference observed was that they came together more readily and completely within one degree, 169°–170° under 730 mm., and at 173°–174°, chiefly at 174°, under a tension of 760 mm., with the mercury column all in the vapor. It is interesting to observe how slightly the boiling point was affected by the removal of the contaminating bodies. Evidently, the principal influence of the latter was in preventing the hydrocarbon from collecting closely at its true boiling point.

The remaining oil was boiled with sodium as long as the metal was affected, and until it remained unchanged on standing with the oil. Even after this treatment was repeated several times, the percentage of carbon was somewhat too high and hydrogen too low: —

0.1503 gram of the oil gave 0.4664 gram CO_2, and 0.2050 gram H_2O.

	Calculated for $C_{10}H_{22}$.	Found.
C	84.51	84.65
H	15.49	15.14

After this purification the specific gravity obtained was 0.7475. For still further certainty as to the purity and composition of this distillate another portion was warmed during several hours with fuming sulphuric acid and shaken thoroughly. After washing and standing over sodium, it was analyzed: —

0.1754 gram of the oil gave 0.5431 gram CO_2, and 0.2442 gram H_2O.

	Calculated for $C_{10}H_{22}$.	Found
C	84.51	84.45
H	15.49	15.47

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In the latter treatment the acid solution when neutralized with baric carbonate gave a barium salt in clusters of needles, sparingly soluble in water, doubtless the barium salt of cymol-sulphonic acid, although the quantity obtained was too small for analysis.

After this prolonged treatment with the fuming acid, the specific gravity was found to be 0.7467, substantially the same as in the previous determinations, and practically the same as the specific gravity of the decane boiling at 163°.

The molecular weight of this hydrocarbon, as determined by the Beckmann method, using benzol as a solvent, was found to be 144; since the formula $C_{10}H_{22}$ requires 142, this determination leaves no doubt that this body is decane, and not a higher homologue.

The chlorine derivatives of the decane 173°–174° were formed in the same manner as those of its isomer. 32 grams of the purified distillate was allowed to absorb 9 grams of chlorine, and the product was fractioned *in vacuo*. After the fourth distillation a small quantity collected at 130°–140°, which gave percentages of carbon, hydrogen, and chlorine required for monochlordecane: —

I. 0.2082 gram of the product gave 0.1699 gram AgCl.
II. 0.2003 of the product gave 0.5038 gram CO_2, and 0.2150 gram H_2O.

	Calculated for $C_{10}H_{21}Cl$.	Found. I.	Found. II.
C	68.00		68.61
H	11.90		11.93
Cl	20.11	20.19	

The specific gravity of this chlordecane at 20° was 0.8874, a value somewhat lower than the specific gravity of the chlordecane formed from 163° decane, 0.8914. After the study of its other properties not enough of this chlordecane remained for a determination of its boiling point under atmospheric pressure. As the specific gravity of the chlorine derivative of petroleum decane, Lemoine * gave 0.908. This value must have been obtained from decane boiling at 162°, since the French chemists have never recognized a decane in petroleum boiling at 173°. It was probably obtained in an impure product, since it is very considerably higher than our determination, which was made, as already shown, in chlordecane from well purified decane.

In continuing the vacuum distillation of the chlorine products from

* Bull. Soc. Chim., XLI. 165.

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173° decane, a considerable quantity collected at 170°–171°, 80 mm., which distilled at 235°-240°, 747 mm. Its composition was shown by analysis: —

0.2008 gram of the oil gave 0.4121 gram CO_2, and 0.1641 gram H_2O.
0.2540 gram of the oil gave 0.3532 gram AgCl.

	Calculated for $C_{10}H_{20}Cl_2$.	Found. I.	II.
C	56.87	55.96	
H	9.48	9.08	
Cl	33.65		34.38

This substance is, therefore, a dichlordecane. The quantity of the dichlordecane was barely sufficient for a determination of its specific gravity; it gave at 20°, 1.0126.

The presence of a decane at 174° seems therefore to be established in Pennsylvania petroleum, confirming the observations of Warren, who alone of all those who have examined American petroleum found a body at this point. If Pelouze and Cahours had carried their course of distillations sufficiently far, they could not have failed to discover this body, since it forms such a large proportion of the higher boiling petroleum distillate. Those chemists did, however, collect a distillate at 180°–182° which gave analytical values and a vapor density very closely supporting the formula $C_{11}H_{24}$. For some time I was in doubt as to whether a distillate might not persist at this point, and it was only after a prolonged series of separations that it was possible to separate the distillates 180°–182° entirely into higher and lower limits, thus supporting the conclusion of Warren, that Pennsylvania petroleum contains no hydrocarbon in appreciable quantity boiling in the vicinity of 180°.

Hendecane, $C_{11}H_{24}$, 196°.

With increasing boiling points the distillates showed less stability, as indicated by more color in the residue in a long course of distillations, although this was not sufficient to interfere with the collection of a homogeneous body within narrow limits of temperature. Between 189° and 192° distillates early began to accumulate, and the quantity gradually increased until 150 c.c. was obtained which distilled entirely at 190°–191° under 730 mm.

On standing over sodium, a portion of this distillate deposited a reddish flocculent precipitate in very appreciable quantity, which indeed was

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observed in all unpurified distillates. On this account very little importance has been attached to the composition of these oils as shown by analysis, except to demonstrate what slight weight can be given to those results. Drying with sodium is indispensable, on account, as shown in another connection, of the difficulty in removing water by other means.

Determinations of carbon and hydrogen in the crude distillate 190°–191° dried over sodium gave the following results: —

0.1521 gram of the oil gave 0.4787 gram CO_2, and 0.1972 gram H_2O.

	Calculated for C_nH_{2n}.	Found.
C	85.71	85.82
H	14.29	14.41

The specific gravity at 20° was found to be 0.7673. After thorough agitation with sulphuric acid and washing with sodic hydrate and water, the specific gravity was scarcely affected, 0.7662.

A comparison of the composition and specific gravity of the crude distillate 190°–191°, 730 mm., as shown above, with the results of Warren and of Pelouze and Cahours, in connection with what follows after further purification, reveals the cause of the lack of uniformity in the earlier work. The specific gravity of Warren's analyzed product, 0.7721 at 15°, which was only purified by boiling with sodium, is substantially the same as that of Pelouze and Cahours, 0.7780 at 20°, which was purified with concentrated sulphuric acid and sodic carbonate, but appreciably higher than the specific gravity of our crude distillate, only dried over sodium. The percentage composition of these products purified in this manner may be more clearly understood if the results of analysis are brought together, as in the following table: —

	Warren.		Mabery.	Pelouze and Cahours.	
	I.	II.		I.	II.
C	85.60	85.33	85.82	84.79	84.58
H	14.80	14.65	14.41	15.42	15.36

Required for	$C_{11}H_{22}$.	$C_{11}H_{24}$.	$C_{12}H_{26}$.
C	85.72	84.62	84.70
H	14.29	15.38	15.30

It is difficult to see how results so closely supporting the formula C_nH_{2n+2} as those of Pelouze and Cahours could be obtained in a product still containing aromatic hydrocarbons, as shown by their method

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of purification and by the higher specific gravity. In the case of this particular hydrocarbon, the method of purification is not especially mentioned, but their general method, which is mentioned under nearly every other member of the long series of hydrocarbons which they examined, consisted in agitating the oil in the cold with concentrated sulphuric acid and washing with sodic carbonate. Then their method included no special means of drying the oil for analysis. It is quite impossible to remove moisture entirely from these hygroscopic oils without the aid of the most vigorous desiccating agents. Nothing less than standing continuously over sodium, in my experience, will insure a perfectly dry condition.

It is evident from the following description of their experiments that Pelouze and Cahours tried the action of reagents on their oil, although they seem not to have suspected the presence of an aromatic hydrocarbon C_nH_{2n-6}: "Le brome, l'acide azotique fumant, l'acide sulfurique au maximum de concentration, l'acide azotique de Nordhausen ne l'attaquent pas à froid. Le mélange des acides azotique et sulfurique agit sur le carbure lorsqu'on maintient ces corps pendant quelque temps en ébullition. Prolonge l'on l'action, on voit se former une petite quantité d'un produit solide et cristallisable. Il se sépare en même temps une huile jaunâtre un peu plus dense que l'eau. De plus, on démèle dans les vapeurs nitreuses l'odeur caractéristique des acides volatils homologues de l'acide acétique."

Upon agitation with nitric and sulphuric acids, the distillate 190°–191° deposited a heavy nitro compound.

Our observations concerning the action of a mixture of concentrated nitric and sulphuric acids in the cold on this distillate do not coincide with those of Pelouze and Cahours. Immediately upon vigorous agitation, a heavy nitro compound separated as a heavy oil, forming a crystalline product on standing. 20 grams of the oil lost 4.5 grams by this treatment, equivalent to 22 per cent of its weight. The nitro compound was very sparingly soluble in hot alcohol, from which it crystallized in needles, melting at 169°–170°. As will be seen later, nitro compounds with the same melting point were separated from Ohio and Canadian petroleum, which do not correspond in melting point to that of either dinitrodurol, 205°, nor of dinitroisodurol, 156°, although crystallization was continued until the melting point was pretty constant. It would have been interesting to obtain sufficient of this substance for more complete examination; but, with the great amount of work on hand in connection with the principal hydrocarbons, it did not seem best to allow our

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attention to be diverted from the main object in view. It should not be understood that the diminution in weight mentioned above on treating with acids was due entirely to the removal of aromatic hydrocarbons. In all the petroleum hydrocarbons we have separated, on treating with nitric and sulphuric acids, a large proportion of the products has remained in solution, and it has been possible to reduce them only very slowly by heating with sodium. From the distillates above 150°, heavy dark brown precipitates have been formed at first, followed by light flocculent deposits resembling aluminic hydrate. On distilling after treating with sodium, usually a considerable residue is left. If heating with sodium be continued until there is no further action, the metal will remain bright in the oil, and we have looked on this as an indication of purity.

The oil separated from the acid mixture was boiled with sodium until it produced no further decomposition, shaken with sulphuric acid, and allowed to stand a long time in contact with sodium. Since the metal remained unaffected, the oil was assumed to be completely purified; nevertheless, analysis showed still remaining a trace of the less hydrogenized body: —

0.1547 gram of the oil gave 0.4816 gram CO_2, and 0.2104 gram H_2O.

	Calculated for $C_{11}H_{24}$.	Found.
C	84.63	84.87
H	15.38	15.12

A determination of the specific gravity of the purified oil gave 0.7585.

To prove with greater certainty the composition of this hydrocarbon, the crude distillate obtained as described above was heated on the steam bath with fuming sulphuric acid, which gave some decomposition, and the oil remaining washed thoroughly with caustic soda and water. 20 grams of the crude distillate gave 16.5 grams of the purified oil, with a loss of 17.5 per cent, which is probably an approximate measure of the proportion of aromatic hydrocarbons in this distillate. It is probable that the loss in weight with the mixture of nitric and sulphuric acids included some decomposition of the principal hydrocarbon. The oil treated with fuming sulphuric acid was carried through ten distillations, after which it collected for the most part within one degree, and 100 grams distilled at 196°–197°, under 760 mm., and with the mercury column all in the vapor. This product was again warmed with fuming sulphuric acid, washed, and dried over sodium.

In the latter experiment the acid was only slightly discolored. The

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oil gave the faint characteristic odor of these hydrocarbons, which is easily recognized when the impurities are removed. It then gave percentages of carbon and hydrogen required for a hydrocarbon of the series C_nH_{2n+2}.

I. 0.1502 gram of the oil gave 0.4665 gram CO_2, and 0.2090 gram H_2O.

II. 0.1661 gram of the oil gave 0.5157 gram CO_2, and 0.2322 gram H_2O.

	Calculated for $C_{11}H_{24}$.	Found. I.	Found. II.
C	84.62	84.70	84.67
H	15.38	15.46	15.53

The specific gravity of the oil 196°–197°, after purification in this manner, was found to be 0.7581. The close agreement in specific gravity of the products after treatment with the mixture of nitric and sulphuric acids, and with fuming sulphuric acid, as well as the proportions of carbon and hydrogen, indicate that the oil was quite thoroughly purified.

That the formula of the purified hydrocarbon boiling at 196° is $C_{11}H_{24}$, and not the next higher homologue, receives further support by a determination of its molecular weight, in which Mr. Hudson obtained, by the Beckmann method, the value 157, required for $C_{11}H_{24}$, 156.

In the preparation of the chlorine derivatives of the hydrocarbon $C_{11}H_{24}$, boiling point 196°, Pennsylvania petroleum. 40 grams of the oil was allowed to absorb 14 grams of chlorine, and the chlorine product was fractioned *in vacuo*. After five distillations, 10 c.c. collected at 145°–150° (80 mm.), that distilled with decomposition at 225°–230°, bar. 747 mm. This product gave on analysis percentages of carbon, hydrogen, and chlorine required for $C_{11}H_{23}Cl$: —

I. 0.2291 gram of the substance gave 0.1713 gram AgCl.

II. 0.1933 gram of the substance gave 0.4914 gram CO_2, and 0.2071 gram H_2O.

	Calculated for $C_{11}H_{23}Cl$.	Found. I.	Found. II.
C	69.29		69.30
H	12.07		11.91
Cl	18.13	18.49	

The specific gravity of monochlorhendecane at 20° was found to be 0.8721. Pelouze and Cahours found that the hydrocarbon which they

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collected at 196°–200° absorbed chlorine at a gentle heat with the formation of a monochlor derivative that boiled at 242°–245° with a specific gravity of 0.9330 at 22°. These values are much in excess of the determinations given above. Our boiling point under atmospheric pressure was only approximate, since the chlorine product was considerably decomposed at those temperatures. In the action of chlorine, the substitution proceeded with the greatest readiness as soon as the chlorine came in contact with the hydrocarbon. No heat was necessary, although, if the action proceeded rapidly, much heat was developed.

The composition of the product obtained by Pelouze and Cahours corresponds to the formula $C_{12}H_{25}Cl$, as shown by the following record of their analyses : —

	Calculated for $C_{12}H_{25}Cl$.	Found
C	70.41	70.34
H	12.23	12.37
Cl	17.36	17.53

In further support of the formula $C_{11}H_{23}Cl$, Mr. Hudson made a determination of the molecular weight of the chloride by the Beckmann method, using benzol as a solvent, in which he obtained 191 ; the formula $C_{11}H_{23}Cl$ requires 190.

Evidently a dichlorhendecane was also formed in this chlorination, since in the vacuum distillation, about 5 c.c. collected at 190°–200°, that gave a percentage of chlorine two per cent too low for the required value. But the quantity was too small to purify it sufficiently to give acceptable results.

Dodecane, $C_{12}H_{26}$, 214°–216°.

Above 193°, 730 mm., the fractions were very small to 208°, but between 208° and 210° much larger quantities collected, for the most part at 209° to 210°. Without further purification except drying with sodium, the crude distillate was analyzed : —

0.1392 gram of the oil gave 0.4355 gram CO_2, and 0.1845 gram H_2O.

	Calculated for C_nH_{2n}.	Found.
C	85.71	85.33
H	14.29	14.73

A determination of its specific gravity gave 0.7745. After treatment with concentrated sulphuric acid, the specific gravity was not changed, — 0.7744. Another portion of the crude distillate was shaken with nitric

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and sulphuric acids, and allowed to stand several hours. After separation from the small quantity of the heavy nitro product and the acid, the oil was boiled with sodium until there was no further action, and the metal remained unaffected on standing several weeks. The oily nitro product deposited a small quantity of crystals on standing, but not enough to purify for a determination of its melting point.

Purified in this manner, this distillate gave the following results on analysis : —

I. 0.1547 gram of the oil gave 0.4816 gram CO_2, and 0.2104 gram H_2O.

II. 0.1474 gram of the oil gave 0.4562 gram CO_2, and 0.2017 gram H_2O.

	Calculated for $C_{12}H_{26}$.	Found. I.	Found. II.
C	84.72	84.87	84.41
H	15.28	15.12	15.21

Its specific gravity at 20° was found to be 0.7684.

Another portion of the crude fraction 209°–210°, purified by thorough agitation and warming with fuming sulphuric acid, twice repeated, gave the following results on analysis : —

0.1471 gram of the oil gave 0.4537 gram CO_2, and 0.2068 gram H_2O.

	Calculated for $C_{12}H_{26}$.	Found.
C	84.72	84.12
H	15.28	15.63

The specific gravity of the oil after treatment with the fuming acid was 0.7729, somewhat higher than the portion purified with nitric and sulphuric acids. It is quite possible that the purification with fuming sulphuric acid, in this instance, was not capable of removing the contaminating bodies as thoroughly as the other method. The purified hydrocarbon was found to distil completely at 214°–216°, under a tension of 760 mm., and with the mercury column all in the vapor. A determination of its molecular weight by the Beckmann method gave Mr. Hudson 173 ; required for the formula $C_{12}H_{26}$, 170.

In the formation of the chlorine derivatives from the hydrocarbon $C_{12}H_{26}$, Pennsylvania petroleum, 95 grams of the purified hydrocarbon was exposed to the action of chlorine until 30 grams was absorbed. Apparently chlorine substitutes as readily in the hydrocarbons of higher,

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as in those of lower boiling points. In fractioning under 80 mm. after six distillations, about 20 c.c. collected at 142°–153°, which distilled at 230°–235° atmospheric pressure. In none of the distillates of chlorine derivatives was hydrochloric acid detected as a product of decomposition when distilled *in vacuo*. Under atmospheric pressure it was impossible to carry on these distillations without serious decomposition. The composition of this fraction corresponded to that of $C_{12}H_{25}Cl$.

I. 0.1910 gram of the oil gave 0.1385 gram AgCl.

II. 0.1339 gram of the oil gave 0.3434 gram CO_2, and 0.1423 gram H_2O.

	Calculated for $C_{12}H_{25}Cl$.	Found. I.	Found. II.
C	70.42		69.93
H	12.23		11.81
Cl	17.36	17.93	

In determining the specific gravity of this chlorine derivative at 20°, it gave 0.8919. A determination of its molecular weight by the Beckmann method, with benzol as a solvent, gave Mr. Hudson 200; required for $C_{12}H_{25}Cl$, 204. The chloride formed by Pelouze and Cahours from their distillate 216°–218° boiled at 258°–260°, somewhat higher than the boiling point of the chloride described in this paper. From the results of their analyses, they deduced the formula $C_{13}H_{27}Cl$.

The chlorination of this product was not carried far enough to form sufficient of the dichlor derivative to separate it by distillation. The greater part of the oil after chlorination distilled at 212°–214°, the boiling point of the hydrocarbon.

A description of these experiments, which are intended to establish the composition of the hydrocarbon distilling at 214°–216°, should not be concluded without a statement of the relation they sustain to those of Warren and of Pelouze and Cahours, the only experimenters who have hitherto attempted the separation of this constituent from American petroleum. The two determinations most nearly concerned in this discussion are specific gravity and percentage composition. In the following comparison of specific gravity determinations and percentage composition, it should be borne in mind that Warren purified his distillate only by boiling with metallic sodium, Pelouze and Cahours by agitation with concentrated sulphuric acid and washing with sodic carbonate; with those results are brought together the determinations described in this paper in the crude distillate, after agitation with concentrated sulphuric acid, and after more thorough purification with the acid mixture: —

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	Warren, 15°.		Pelouze & Cahours, 20°.		Crude Distillate.	Mabery, 20°. Agitation with H_2SO_4.	Purified.	
Sp. gr.	0.7804		0.7960		0.7745	0.7744	0.7684	
	I.	II.	I.	II.			I.	II.
C	84.66	85.74	84.58	84.51	85.33		84.87	84.41
H	14.85	14.66	15.37	15.45	14.73		15.12	15.21

The percentages of carbon and hydrogen required for the formula $C_{12}H_{26}$ are, C 84.72, H 15.30; for the formula $C_{12}H_{28}$, C 84.78, H 15.22. Evidently the differences in percentage composition are not sufficient to distinguish by analysis alone which of the two formulas is the correct one. But the differences between either of these formulas and the formula $C_{12}H_{24}$, C 85.71, H 14.29, should be readily shown by analysis.

Having at hand a portion of the purified distillate 214°–216° that had been treated with chlorine and the part not chlorinated distilled, I continued the distillation until the chlorine derivatives were completely removed, and the hydrocarbon was treated with fuming sulphuric acid and distilled over sodium. It then gave as its specific gravity 0.7729, substantially the same as before chlorination. Normal dihexyl prepared by the action of zinc and hydrochloric acid on normal hexyl iodide boils at 214°.5 and apparently is identical with a hydrocarbon having the same composition, obtained by electrolysis of potassium œnanthylate (Schorlemmer). The latter has the specific gravity 0.7738 at 17°. It is therefore probable that the hydrocarbon $C_{12}H_{26}$, boiling at 214°–216°, from American petroleum, has the same form. The purified hydrocarbon then gave the following percentages of carbon and hydrogen: —

I. 0.1599 gram of the oil gave 0.4978 gram CO_2, and 0.2177 gram H_2O.

II. 0.1617 gram of the oil gave 0.5021 gram CO_2, and 0.2270 gram H_2O.

III. 0.1559 gram of the oil gave 0.2193 gram H_2O. The CO_2 was lost.

	Calculated for $C_{12}H_{26}$.	Found. I.	II.	III.
C	84.72	84.89	84.69	
H	15.28	15.10	15.31	15.63

These results indicate the absence of any impurity not readily acted on by chlorine.

As one of the results of this examination it can, I think, be safely asserted that the constituents of Pennsylvania petroleum with boiling points at 163°–164°, 173°–174°, 196°–197°, and at 215°–216°, constitute

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the main body of this petroleum within these limits, and whatever other bodies may be present, they are to be found only in comparatively small quantities. As to the proportion of aromatic hydrocarbons in the crude oil, no direct estimation can be based on these observations.

Fuming sulphuric acid removed 40 per cent of the crude distillate 160°–161°, leaving decane as the remaining 60 per cent. Whether the portion removed was mesitylene alone may be questionable, but no doubt it formed the larger part of the body uniting with the fuming acid. Even in such prolonged fractional separations as those described in this paper, it cannot be assumed that nearly all the decane 163°–164° was collected in the fractions which should contain it, neither is it probable that the crude distillate from which was selected the specimen for the separation of these constituents contained all the decane in the corresponding quantity of crude oil. But it is evident that the aromatic hydrocarbons are present in no inconsiderable amounts, and without doubt these bodies have much influence on the illuminating qualities of the oil. As shown by the slight changes in specific gravity after the action of ordinary concentrated sulphuric acid, the action of this acid in the usual method of refining does not include to any considerable extent the removal of the aromatic hydrocarbons. Its beneficial action seems to concern more especially the decomposition products of distillation and certain constituents present in minute quantities, such as the unsaturated hydrocarbons, the oxygen, and nitrogen compounds. It scarcely need be mentioned that this applies to the action of sulphuric acid in the cold. When heated, without doubt a part of the aromatic hydrocarbons would be removed, to the detriment of the burning qualities. The formation of barium salts from all the distillates treated with fuming sulphuric acid proves the presence in appreciable amounts of a wide range of aromatic hydrocarbons.

Without reference to the percentages of carbon and hydrogen, the low specific gravity of the hydrocarbons described above is sufficient to show that they are not naphtenes. The following comparison of the unpurified distillates and the purified hydrocarbons as regards their specific gravity with the naphtenes separated by Markownikoff from the Russian oil will perhaps make these differences more clearly understood.

Baku naphtenes: —

	B. P.	Specific Gravity.
$C_{10}H_{20}$	160°–162°	0.795 (0°)
$C_{11}H_{22}$	180°–182°	0.8119 (0°)
$C_{12}H_{24}$	196°–197°	0.8055 (14°)

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Pennsylvania C_nH_{2n+2} : —

	B. P.	Specific Gravity at 20°. Purified.	Unpurified.
$C_{10}H_{22}$	163°–164°	0.7479	0.7684
$C_{10}H_{22}$	173°–174°	0.7467	0.7502
$C_{11}H_{24}$	196°–197°	0.7581	0.7673
$C_{12}H_{26}$	214°–216°	0.7676	0.7745

Another important result of this study is the evidence that the main body of the hydrocarbons in Pennsylvania petroleum within these limits of temperature are members of the series C_nH_{2n+2}. Satisfactory analytical data in proof of this conclusion have cost a vast expenditure of time and effort, not only in the routine labor of separation and purification, but in obtaining sufficiently close percentages of carbon and hydrogen. In such a large number of determinations the ordinary method of combustion becomes exceedingly tedious, since all details must be watched with the greatest care. In the beginning of analysis there was not the slightest evidence as to whether the hydrocarbons were of the series C_nH_{2n+2}, or of the series C_nH_{2n}. The extreme hygroscopic nature of these bodies was not then appreciated, nor the refinement in purification necessary to yield acceptable results. Many analyses were made before these details were fully understood.

Constituents of Ohio Trenton Limestone Petroleum.

The constituents of Ohio petroleum between 160° and 216° were sought for in vacuum distillates obtained from the crude oil, as described in a former paper.*

Distillation *in vacuo* was continued until all portions had collected that could be brought together within the desired limits. Further concentration was carried on under atmospheric pressure, since this did not occasion serious decomposition. Probably no petroleum distillates with such high boiling points can entirely escape decomposition in a long course of distillations, but small amounts of decomposition products can no doubt be removed by sulphuric acid, leaving the main body of the oil free from contamination. After the first distillations *in vacuo* Ohio distillates seem to suffer no more change during distillation than those from Pennsylvania oil. Before separation into two degree fractions, the sulphur compounds were removed so far as possible by precipitation with mercuric chloride. As the distillation proceeded, the characteristic

* Proc. Amer. Acad., XXXI. 25.

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"heaps" began to appear in the vicinity of 160°, 730 mm., falling off below 158° and above 163°. These portions were therefore carried through a long course of separations, fifty altogether, forty-five within one degree, after which they collected mainly at 159°–162°. A combustion of the crude distillate 159°–160°, purified as explained above only by mercuric chloride, gave the following results: —

I. 0.1591 gram of the oil gave 0.4983 gram CO_2, and 0.2076 gram H_2O.

	Calculated for $C_{10}H_{20}$.	Calculated for $C_{10}H_{22}$.	Found.
C	85.71	84.51	85.41
H	14.29	15.49	14.50

On the basis of these values alone, there should be no hesitation in assigning to this oil the formula $C_{10}H_{20}$. The specific gravity of this distillate was found to to be 0.7717. Its vapor density was determined by the Hofmann method: —

0.1272 gram of the oil gave 67 c.c. of vapor at 182°, and under a tension of 374.4 mm.

Calculated for $C_{10}H_{22}$.	Found.
4.92	4.96

After treatment with ordinary concentrated sulphuric acid, another portion of this distillate gave 0.7678 as its specific gravity, and the following percentages of carbon and hydrogen: —

0.1416 gram of the oil gave 0.4452 gram CO_2, and 0.1855 gram H_2O.

C	85.76
H	14.56

Agitation of the crude distillate in the cold with a mixture of concentrated nitric and sulphuric acids caused the separation of a heavy oil that deposited crystals of a nitro product on standing. After crystallization from hot alcohol, in which it is sparingly soluble, this substance melted at 229°, showing it to be *trinitromesitylene*, melting point 230°–232°. Complete removal of the nitro compound from decane required prolonged boiling with sodium followed by agitation with sulphuric acid. The hydrocarbon then no longer attacked the metal, nor tarnished it on long standing. Purified in this manner, this oil gave values required for decane: —

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0.1512 gram of the oil gave 0.4677 gram CO_2, and 0.2088 gram H_2O.

	Calculated for $C_{10}H_{22}$.	Found.
C	84.51	84.35
H	15.49	15.35

For further assurance as to the composition of this hydrocarbon, another portion of the crude distillate was first agitated in the cold with fuming sulphuric acid, which produced no heat, and then heated with the acid on the steam bath. As in most of the crude oils when treated in this manner, the acid turned dark when heated, and evidently extracted a considerable proportion of the oil. After washing with sodic hydrate and water, the remaining oil gave only the faint odor characteristic of the petroleum hydrocarbons. In many of the analyses, it will be seen that the percentage of hydrogen is somewhat lower than should be expected in a pure substance. This deficiency is doubtless due to a very small proportion of the hydrocarbon with less hydrogen, the last traces of which it is somewhat difficult to remove. The fraction 160°–162°, after the last purification, contained the following percentages of carbon and hydrogen : —

0.1532 gram of the oil gave 0.4740 gram CO_2, and 0.2113 gram H_2O.

	Calculated for $C_{10}H_{22}$.	Found.
C	84.51	84.38
H	15.49	15.33

A determination of its specific gravity at 20° gave 0.7535, a value slightly higher than the specific gravity of the corresponding fraction of the Pennsylvania oil, doubtless due to the slight trace of impurity still remaining. In determining the molecular weight of this decane by the method of Beckmann, Mr. Hudson obtained 145; required for $C_{10}H_{22}$, 142.

The boiling point of this hydrocarbon, so thoroughly purified that neither fuming nitric acid nor fuming sulphuric acid produced further change, was found to be nearly the same as that of 163° decane from Pennsylvania petroleum. 50 c.c. distilled entirely between 162°.5 and 163°.5 under a barometric pressure of 757.5 mm.

Since even a larger proportion of the crude distillate was removed in combination with fuming sulphuric acid than from the Pennsylvania distillate 163°, an attempt was made to ascertain the composition of the barium salt, formed by neutralizing with baric carbonate and crystallizing the filtered solution, after boiling with bone black. A considerable

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quantity of the barium salt crystallizing in needles was obtained, and the percentage of barium found, 25.95, agreed closely with the theoretical percentage of barium in barium mesitylene sulphonate $(C_9H_{11}SO_3)_2Ba$, 25.61. But the salt proved to be anhydrous, while according to Jacobson,* barium mesitylene sulphonate crystallizes with 9 H_2O. On account of the limited supply of the barium salt, it was not possible to verify this determination by further study; but there can be no doubt of the possibility of forming a barium salt of mesitylene sulphonic acid in this manner, since trinitromesitylene melting at 225°–230°, melting point of trinitro mesitylene, 230°, was formed without difficulty by the action of fuming nitric acid on this distillate.

As further evidence of the composition of the hydrocarbon 163° Ohio petroleum, 46 grams well purified with fuming sulphuric acid was exposed to the action of chlorine until the weight had increased 11 grams. The chlorinated product was fractioned twelve times under 80 mm., when 15 c.c. collected at 130°–135°, distilling at 200°–208° atmospheric pressure. It was shown by analysis to have the composition required for $C_{10}H_{21}Cl$.

I. 0.2340 gram of the substance gave 0.1934 gram AgCl.

II. 0.1935 gram of the substance gave 0.4785 gram CO_2, and 0.2119 gram H_2O.

III. 0.1715 gram of the oil gave 0.4246 gram CO_2, and 0.1963 gram H_2O.

	Calculated for $C_{10}H_{21}Cl$.	Found. I.	II.	III.
C	68.00		67.44	67.53
H	11.90		12.17	12.73
Cl	20.11	20.45		

In a determination of its specific gravity at 20°, this chlordecane gave 0.8958. In continuing the distillation of the chlorine product after the twelfth fraction, 10 c.c. collected at 160°–170°, specific gravity, 1.0627 at 20°, which gave the percentages of carbon, hydrogen, and chlorine required for $C_{10}H_{20}Cl_2$.

I. 0.2984 gram of the substance gave 0.4105 gram AgCl.

II. 0.2753 gram of the substance gave 0.5746 gram CO_2, and 0.2356 gram H_2O.

	Calculated for $C_{10}H_{20}Cl_2$.	Found. I.	II.
C	56.87		56.94
H	9.47		9.51
Cl	33.65	34.03	

* Ann. Chem. Pharm., XLVI. 95.

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Normal Decane, B. P. 173°–174°.

Above 162° (730 mm.), the distillates were small to 163°. After long continued distillation, 300 grams collected at 169°–170° (730 mm.), which, without further purification, except drying over sodium, gave the following percentages of carbon and hydrogen: —

I. 0.1434 gram of the oil gave 0.4486 gram CO_2, and 0.1927 gram H_2O.
II. 0.1577 gram of the oil gave 0.4948 gram CO_2, and 0.2070 gram H_2O.

	Calculated for		Found.	
	$Cl_{10}H_{28}$.	$Cl_{10}H_{20}$.	I.	II.
C	84.51	85.71	85.33	85.55
H	15.49	14.29	14.94	14.58

A determination of the specific gravity of this distillate gave 0.7621, a value considerably higher than that of the corresponding unpurified Pennsylvania distillate, 0.7502.

0.1670 gram of the oil gave 79 c.c. of vapor at 182°, under a tension of 366 mm.

Calculated for $C_{10}H_{22}$.	Found.
4.90	5.15

A portion of the crude distillate was shaken with concentrated sulphuric acid, washed, and dried for analysis: —

0.1504 gram of the oil gave 0.4708 gram CO_2, and 0.1984 gram H_2O.

C	85.37
H	14.67

The specific gravity of this oil after treatment with sulphuric acid was somewhat lower than that of the crude distillate, 0.7580. A determination of its vapor density gave 5.02. The fraction 169°–170°, Ohio oil, was the first to be submitted to the action of the mixture of nitric and sulphuric acids. When a small quantity of the oil was heated to about 125° during 24 hours with the acid mixture, nitrous fumes were freely evolved and the volume of the oil gradually diminished until very little remained. Upon diluting the acid, a heavy, tarry mass was precipitated, evidently a product of decomposition of the hydrocarbon. In another experiment, 25 grams of the crude distillate were agitated in the cold with the acid mixture, separated from the acid and the oily nitro product, washed, and dried. After boiling with sodium and shaking with sulphuric acid, there

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remained of the quantity taken 17 grams, with a loss of 32 per cent. A portion of the nitro product crystallized on standing, and after several crystallizations from hot alcohol, in which it was sparingly soluble, the melting point could not be raised above 164°–165°. In testing the action of sulphuric acid alone on the distillate 171°–172°, 25 grams of the crude oil was agitated with three successive portions of concentrated sulphuric acid, washed with sodic hydrate and water, and dried. In the first treatment, in which the oil lost in weight 1.8 grams, the acid was badly discolored; the subsequent portions were not affected. The oil was next heated gently with fuming sulphuric acid with agitation, which caused considerable blackening, washed first with concentrated sulphuric acid, then with sodic hydrate and water, and dried. After the last treatment, the oil weighed 19.8 grams, with a loss of 25 per cent.

It is evident from these observations that some care is necessary in attempting to purify these hydrocarbons with concentrated nitric acid. In the cold or under a gentle heat not prolonged, the decomposition is probably not serious. But at higher temperatures, as shown above, the action may proceed too far. The purified oil gave satisfactory results on analysis : —

I. 0.1373 gram of the oil gave 0.4247 gram CO_2, and 0.1900 gram H_2O.

II. 0.1459 gram of the oil gave 0.4520 gram CO_2, and 0.2090 gram H_2O.

	Calculated for $C_{10}H_{22}$.	Found. I.	II.
C	84.51	84.36	84.47
H	15.49	15.38	15.92

Two determinations of the specific gravity at 20° of this oil in different preparations gave 0.7519 and 0.7513.

In a still more extended purification, some of the crude distillate was agitated thoroughly with the mixture of nitric and sulphuric acids, allowed to stand several hours with the acids, and, after washing, heated for some time with tin and hydrochloric acid. The washed and dried oil was then warmed with fuming sulphuric acid, washed, dried, and distilled. It then gave 0.7482 as its specific gravity at 20°, more nearly approaching the specific gravity of the Pennsylvania decane 173°, 0.7467, and analysis indicated that the remaining oil had the composition of the general formula C_nH_{2n+2} : —

0.1449 gram of the oil gave 0.4494 gram CO_2, and 0.2051 gram H_2O.

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	Calculated for $C_{10}H_{22}$.	Found.
C	84.51	84.57
H	15.49	15.73

Another quantity of the crude distillate was heated on the steam bath during several hours with fuming sulphuric acid, occasionally shaking the acid with the oil, boiled with sodium, distilled, and dried for analysis: —

0.1519 gram of the oil gave 0.4715 gram CO_2, and 0.2085 gram H_2O.

C	84.67
H	15.26

The specific gravity of this product was the same as before, 0.7514. In a determination of the molecular weight of the hydrocarbon purified by the mixture of nitric and sulphuric acids, tin and hydrochloric acid, fuming sulphuric acid and sodium, Mr. Hudson obtained 142; required for $C_{10}H_{22}$, 142. The fuming sulphuric acid solution separated from the oil was neutralized with baric carbonate filtered and evaporated nearly to dryness. On cooling, a barium salt separated in needles, which were very sparingly soluble in cold water. The air-dried salt was anhydrous, and it gave, by ignition with sulphuric acid, 25.46 per cent of barium. Hexahydrocymol requires 23.8 per cent of barium, and iso-cymol 24.3. The first hydrocarbon boils at 171°–172°, m-cymol at 174°–176°, p-cymol at 172°–173°, and pseudo-cymol at 169°. By fuming sulphuric acid at least the iso-cymol if present in petroleum should be extracted, and it is probable that this barium salt was an impure compound of cymolsulphonic acid. That the decane boiling at 174° is the principal constituent of Ohio petroleum at this point, and that it contains a considerable proportion of aromatic hydrocarbons, has received ample proof. As to the precise form of the aromatic hydrocarbons, the quantity of material it has been expedient to manipulate in purifying the decane was not sufficient to demonstrate. It would evidently be impossible to separate these bodies from decane in any course of distillation, and it would require a large quantity of the crude distillate, although not so thoroughly distilled as the one prepared in this examination.

In still further evidence as to the formula of this hydrocarbon, the chlorine derivatives were prepared by the action of chlorine on a portion purified with the mixture of nitric and sulphuric acids and sodium. 83 grams of the hydrocarbon was allowed to absorb 30 grams of chlorine, the theoretical quantity for the mono derivative being 20 grams. As an illustration of the readiness with which substitution

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takes place, in this experiment the stream of chlorine happened to be exceptionally vigorous, but it was completely absorbed from the beginning to the extent of 5 grams during the first ten minutes. Hydrochloric acid escaped from the oil with brisk effervescence, although the chlorine was delivered at some distance above the surface of the oil. This rapid substitution at low temperatures is quite unlike the substitution of chlorine in dekanaphtene observed by Markownikoff and Oglobine, as shown by the following statement:* "Lorsqu'on fait agir du chlore sec sur les vapeurs du décanaphtène en ébullition et sous l'influence de l'insolation directe, la réaction se fait lentement avec dégagement d'acide chlorhydrique et demande un très grand excès de chlore en comparaison de ce qu'il en faut d'après le calcul théorique." Yet in the residue of the hydrocarbon not acted on by chlorine, Markownikoff and Oglobine found a somewhat lower percentage of carbon and a higher percentage of hydrogen, from which, together with a slightly lower specific gravity, 0.792, than decanaphtene, 0.795, they infer that "ces chiffres semblent indiquer la présence d'une quantité notable d'un hydrocarbure saturé." In accordance with my observations on all the hydrocarbons from Pennsylvania, Ohio, and Canadian oil which I have chlorinated, these bodies should be saturated long before the naphtenes, especially if the latter substitute chlorine slowly at a boiling temperature.

In fractioning *in vacuo* under 80 mm. the chlorinated oil, after several distillations about 8 c.c. collected at 134°–136°, with a small proportion of unaffected hydrocarbon which came over at a lower temperature. Analyses of this product gave numbers corresponding to the composition of chlordecane:—

I. 0.2773 gram of the oil gave 0.6977 gram CO_2, and 0.2886 gram H_2O.

II. 0.1623 gram of the oil gave 0.4085 gram CO_2, and 0.1679 gram H_2O.

III. 0.2117 gram of the oil gave 0.1707 gram AgCl.

	Calculated for $C_{10}H_{21}Cl$.	Found. I.	II.	III.
C	68.00	68.60	68.64	
H	11.90	11.56	11.50	
Cl	20.11			19.93

A determination of the specific gravity of this chlordecane at 20° gave 0.8895. Under atmospheric pressure, it distilled with some decomposi-

* Ann. Chim. Phys., (6.), II. 453.

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tion at 205°–210°. Its molecular weight, determined by the Beckmann method, was found by Mr. Hudson to be 174; required for the formula $C_{10}H_{21}Cl$, 176.5.

In continuing the fractional distillation *in vacuo* of the chlorine product from 173° Ohio decane, a small quantity, 3 c.c., collected at 170°–180°, 80 mm., which distilled under atmospheric pressure at 240°–243°. On account of decomposition, this portion was fractioned only five times, but it gave on analysis a percentage of chlorine corresponding to dichlordecane: —

I. 0.2690 gram of the oil gave 0.5549 gram CO_2, and 0.2191 gram H_2O.

II. 0.2753 gram of the oil gave 0.5746 gram CO_2, and 0.2111 gram H_2O.

III. 0.3147 gram of the oil gave 0.4256 gram AgCl.

	Calculated for $C_{10}H_{20}Cl_2$.	Found. I.	II.	III.
C	56.87	56.24	56.94	
H	9.48	9.04	8.51	
Cl	33.65			33.46

A determination of the specific gravity of this dichlordecane at 20° gave 1.0300, which may not be strictly correct on account of the small quantity of the material.

In determining the boiling point of this decane, 50 c.c. of the oil, purified as thoroughly as possible, distilled at 173°.6–174°.6, mostly below 174°, under a tension of 760 mm. and with the mercury column all within the vapor.

The boiling point of normal decane was given by Krafft * as 173° at 760 mm., but 0.7304, its specific gravity at 20°, is sensibly lower than it has been possible to reduce the decane from petroleum. Whether this be due to the presence of a small amount of decanaphtene, which appears to be nearly inert toward the methods of purification that have been applied to these petroleum hydrocarbons, can only be determined in more extended experiments. In view of the ease in chlorination of the hydrocarbons C_nH_{2n+2}, and the difficulty in chlorinating the naphtenes according to the experience of Markownikoff and Oglobine, perhaps fractional chlorination should permit of the removal of decane, and the naphtene would reveal its presence by analysis. As already

* Ber. der deutsch. chem. Gesellsch., XV. 1695.

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shown in the case of Pennsylvania dodecane, page 141, the portion remaining after incomplete chlorination is the purified hydrocarbon $C_{12}H_{26}$.

Hendecane, $C_{11}H_{24}$, 195°–196°.

Above 173° (760 mm.), fractions collected irregularly and in small amounts to 188°. There was no indication of an accumulation in the vicinity of 180°, but after precipitation of the sulphur compounds with $HgCl_2$ considerable quantities collected at 188°–192° (730 mm.), which for the most part came together at 189°–191°. An analysis of the crude distillate gave the following percentages of carbon and hydrogen: —

0.1444 gram of the oil gave 0.2536 gram CO_2, and 0.1888 gram H_2O.

	Required for C_nH_{2n}	
C	85.71	85.67
H	14.29	14.53

A specific gravity determination at 20° gave 0.7789, and a determination of its vapor density by the Hofmann method the following value: —

0.1286 gram of the oil gave 67 c.c. of vapor at 182°, and under 357.5 mm.

Calculated for $C_{11}H_{22}$.	Found.
5.33	5.26

As in the corresponding crude Pennsylvania distillate, the percentage composition of this hendecane based on the above analysis supports the formula C_nH_{2n}, and it is nearly the same as the specific gravity found by Warren, which gave the formula C_nH_{2n}; it is even closer to the value 0.7780, found by Pelouze and Cahours in their distillate from Pennsylvania, or rather from American petroleum. Allusion is made in their papers to distillates prepared from Canadian petroleum, as well as from Pennsylvania petroleum, and their high specific gravity, much higher than Pennsylvania distillates yield, would seem to indicate that they had in hand Canadian distillates. Another portion of the crude distillate 189°–190° was agitated with a mixture of nitric and sulphuric acids, and allowed to stand some time after the heat of the first reaction had moderated. A heavy nitro compound separated, which crystallized on standing. The reaction was far more energetic than in the same distillate from Pennsylvania petroleum, probably on account of a larger proportion of aromatic hydrocarbons. A heavy nitro compound immediately separated as an oil, which crystallized on standing. It was purified by crystallization from

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alcohol, in which it is very sparingly soluble, and gave as its melting point 158°–160°, which was not changed by several crystallizations. There are several aromatic hydrocarbons whose boiling points are in this vicinity, but only one forms a nitro derivative with this melting point, isodurol, whose trinitro derivative melts at 156°. It would be interesting to examine these nitro products more fully, but for want of time and material nothing further was done with them.

The specific gravity of the oil was very sensibly diminished by the action of the acid mixture. The first determination gave 0.7688, which was not diminished by further treatment, although this value is somewhat higher than the specific gravity of the Pennsylvania distillate, 0.7581. In determining the boiling point of this product, 50 c.c. distilled entirely at 195°–196°, mostly at 196°, under a tension of 760 mm. After purification of a portion of the crude distillate with fuming sulphuric acid, different preparations of the washed and dried oil gave in the hands of different analysts the following percentages of carbon and hydrogen: —

I. 0.1508 gram of the oil gave 0.4683 gram CO_2, and 0.2055 gram H_2O.

II. 0.1520 gram of the oil gave 0.4715 gram CO_2, and 0.2109 gram H_2O.

III. 0.1523 gram of the oil gave 0.4733 gram CO_2, and 0.2180 gram H_2O.

	Calculated for $C_{11}H_{22}$.	Found. I.	II.	III.
C	84.63	84.70	84.61	84.75
H	15.38	15.15	15.42	15.90

The specific gravity of the purified oil was found to be 0.7737 at 20°, and the vapor density as follows: —

0.1421 gram of the oil gave 68.6 c.c. of vapor at 182° under 373.8 mm.

Calculated for $C_{11}H_{22}$.	Found.
5.33	5.43

A determination of its molecular weight by Mr. Hudson gave 158; required for the formula $C_{11}H_{24}$, 156.

In attempting to form the chlorine derivatives of this hydrocarbon, 16 grams of the fraction 196°, Ohio petroleum, the small amount that remained for this experiment, was treated with chlorine until it gained in weight 4.5 grams. After the chlorine product was fractioned four times

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it collected in very small quantity at 150°–155°. Analysis gave results corresponding to the formula $C_{11}H_{23}Cl$.

I. 0.2042 gram of the substance gave 0.1548 gram AgCl.
II. 0.1938 gram of the oil gave 0.4765 gram CO_2, and 0.2071 gram H_2O.

	Calculated for $C_{11}H_{23}Cl$.	Found. I.	Found. II.
C	69.29		69.74
H	12.07		11.88
Cl	18.63	18.71	

Evidently the chlorination had proceeded so far that the monochlorhendecane could not be separated completely from the dichlor derivative, as shown by the high boiling point, and the large percentage of carbon.

The small amount of the dichlor derivative was not sufficient when purified to give satisfactory analytical data in support of its composition.

Dodecane, $C_{12}H_{26}$, 214°.

Above 193° the distillation was continued longer *in vacuo*. At the end of the eighteenth, between 120° and 130°, 1200 grams collected in single degree fractions, for the most part at 122°–124° and 128°–130°.

The latter distilled under atmospheric pressure at 212°–214°, and was therefore selected for the study of the hydrocarbon which according to the corresponding distillate in Pennsylvania oil should contain $C_{12}H_{26}$. The crude distillate gave the following percentages of carbon and hydrogen : —

	Calculated for $C_{12}H_{26}$.	Found
C	85.51	85.76
H	14.49	14.55

The specific gravity of this distillate at 20° was 0.7877. 25 grams of the crude distillate was heated with fuming sulphuric acid to 50°, and kept warm on the steam bath during several hours. Very little sulphurous acid was set free, although the acid became thick and dark. The loss in weight of the oil was 4.5 grams, or 18 per cent. The remaining oil was washed with sodic hydrate and water, and dried over sodium for analysis.

0.1500 gram of the oil gave 0.4650 gram CO_2, and 0.2088 gram H_2O.

	Calculated for $C_{12}H_{26}$.	Found.
C	84.70	84.54
H	15.30	15.47

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A determination of its specific gravity at 20° gave 0.7867, with scarcely any change by the action of the fuming acid. Another portion of the crude distillate was shaken with a mixture of nitric and sulphuric acids. The great heat of the reaction was controlled by cooling, and the heavy nitro product allowed to separate by standing. The principal reaction was soon over, the nitro compound separating in needles on standing.

In hot alcohol the nitro derivative was readily soluble, but quite insoluble in cold alcohol. It melted at 165°, and was probably a derivative, or perhaps a mixture of derivatives. of the aromatic hydrocarbons with boiling points in this vicinity, such as isohexylbenzol, or isoamylbenzol, boiling points 212°–214°, and quite probably contained in petroleum. After treatment with the acid mixture, the oil was boiled with tin and hydrochloric acid, washed, and boiled with sodium, then distilled. Its boiling point was not appreciably changed, but the specific gravity was reduced to 0.7727, a value practically the same as that of the Pennsylvania dodecane. A determination of its molecular weight by the Beckmann method gave 172; required for $C_{12}H_{26}$, 170.

In forming the chlorine derivates of this hydrocarbon, 35 grams absorbed 8.5 grams of chlorine, and the product was fractioned under 80 mm. After the tenth distillation, about 15 c.c. collected at 150°–160°. In this instance, as in one or two others, the distillate taken for chlorination was not purified, and in the distillation the vapors affected the eyes seriously, doubtless on account of substitution in the side chain in the aromatic hydrocarbons contained in the crude distillate. Either on account of decomposition, or want of sufficient material for complete separation, it was not possible to purify this product sufficiently to give satisfactory numbers on analysis, although the results show the formation of a mono- and a dichlor dodecane. The percentage of chlorine in the distillate 150°–160° came two per cent too low for monochlor dodecane, and no combustion was made. In a higher distillate collected at 190°–200° the following numbers were obtained: —

I. 0.2224 gram of the oil gave 0.2607 gram AgCl.

II. 0.1952 gram of the oil gave 0.4411 gram CO_2, and 0.1816 gram H_2O.

	Calculated for $C_{12}H_{24}Cl_2$.	Found I.	Found II.
C	60.26		61.63
H	10.04		10.33
Cl	29.71	28.99	

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While, therefore, the formula of dodecane in Ohio petroleum is not supported by such reliable data as those of the lower constituents, the presence of this hydrocarbon is established, I think, beyond question.

The principal constituents of Ohio petroleum have been shown to be identical with those of Pennsylvania petroleum. The higher specific gravity and peculiar qualities of the Ohio distillates depend on the larger proportions of aromatic hydrocarbons, and perhaps of other heavy constituents.

Constituents of Canadian Petroleum from the Corniferous Limestone.

In continuing the study of the higher portions of Canadian petroleum, the vacuum distillates 150°–300° * were carried through fifteen additional distillations under 50 mm. As the separations proceeded, the fractions fell 5° or more in boiling points, large portions collecting below 220°, the point where the separations could be continued without serious decomposition under atmospheric pressure. In single degree fractions after the fifth, distillation was continued until the operation had been repeated in all twenty-nine times. As in the other oils, the distillates collected mainly at 159°–161°, 168°–170°, 188°–191°, and 208°–210° (730 mm.). There is even greater necessity in the Canadian than in the Ohio oil that the earlier distillations be carried on *in vacuo*, on account of the greater quantity of sulphur compounds, but more especially, as will be seen in another paper, on account of the greater proportion of unsaturated hydrocarbons and the smaller proportions of the members in question that distill between 160° and 216°. It is, therefore, otherwise impossible to obtain a large proportion of these higher constituents uncontaminated by impurities due to cracking. But the vacuum distillates are free from the intensely disagreeable odors due to cracking, which are far more pronounced than any to be obtained from Ohio oil. Nevertheless, the natural odor of these compounds, however carefully they have been protected from decomposition before purification, is more pungent than those from Ohio oil. Colorless when first distilled, all these distillates become colored on standing, probably on account of polymerism of the unsaturated hydrocarbons alluded to above, and of other unstable bodies resembling the terpenes, which we have good evidence are contained in petroleum. That this is unquestionably the cause of the coloration we have abundant evidence in the polymeri-

* Proc. Amer. Acad., XXXI. 52.

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zation and the formation of heavier oils in these unsaturated bodies after they have been separated and allowed to stand as long as two years. As further evidence that these unstable bodies are the cause of the color, after they have been removed, the purified oils remain colorless permanently. The higher specific gravity observed in the first vacuum distillate from Canadian crude petroleum is still retained in the single degree fractions, however long the fractional distillation is continued. But although these portions are heavier than the distillates from Pennsylvania and Ohio oils, they are so much lighter than the naphtenes that the latter bodies cannot be present in any considerable quantity. In general the ready and abundant formation of nitro derivatives and sulphonic acids is sufficient evidence that the greater specific gravity is due, for the most part at least, to the aromatic constituents. It is quite probable that naphtenes are present in small amounts, and that they are accountable, as has been suggested, for the extreme difficulty in removing the last traces of the less hydrogenized constituents by fuming sulphuric acid, even after vigorous treatment several times repeated. In some instances, nitric and sulphuric acids have given nitro products that have required very long and vigorous boiling with tin and hydrochloric acid for complete reduction, or an equivalent treatment with sodium. Occasionally the reduction with tin and acid has caused the separation of a heavy red oil insoluble in the acid, consequently not an amine.

Decane, $C_{10}H_{22}$, 163°–164°.

The composition of the principal distillates from Canadian petroleum below 150° was found to be represented by the series C_nH_{2n+2}. Above this point the distillates were small to 158°, but between this point and 162° larger amounts collected and remained persistently at 159°–160° (730 mm.). After treatment with fuming sulphuric acid, a portion of this distillate was still further fractioned until 75 grams distilled at 163°–164° under 760 mm., and with the mercury column all in the vapor. In the crude distillate before treatment with the acid, carbon and hydrogen were determined, with no other purification than drying over sodium. No less efficient means of desiccation removes the water sufficiently for analysis. But since a reddish flocculent precipitate separates when any of these distillates stand with sodium, evidently the percentages of carbon and hydrogen in the crude distillates cannot be accurately expressed by the results of combustion. The precipitation is doubtless caused in part by sulphur compounds which are not wholly removed by alcoholic mercuric chloride, although it is observed when the quantity of sulphur is very small.

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0.1610 gram of the oil gave 0.5057 gram CO_2, and 0.1989 gram H_2O.

C	85.67
H	13.72

Before treatment with the acid, a determination of specific gravity at 20° gave 0.7785. After purification with the acid the specific gravity was diminished to 0.7572, nearly the same value as that found in the corresponding fraction of Ohio oil. The penetrating odor of the crude distillate, resembling that of the aromatic hydrocarbons, disappeared entirely after treatment with the fuming acid, and the purified oil gave only the faint characteristic odor of the petroleum hydrocarbons C_nH_{2n+2}. The acid was blackened and gave off much sulphurous acid. 30 grams gave by this treatment 23.4 grams of the purified oil with a loss of 22 per cent. It is interesting to note the higher specific gravity of the unpurified distillate 163°–164° in all these oils — Pennsylvania, Canadian, and Ohio — than that of the higher distillate, 174°. This clearly indicates a larger percentage of mesitylene and perhaps of decanaphtene. The difficulty in removing entirely the heavier body would seem to indicate a trace of the latter.

After the last distillation, the oil was again treated with the fuming acid and dried over sodium for analysis: —

0.1723 gram of the oil gave 0.5358 gram CO_2, and 0.2304 gram H_2O.

	Calculated for $C_{10}H_{20}$	Calculated for $C_{10}H_{22}$	Found.
C	85.71	84.51	84.82
H	14.29	15.49	14.85

The oil was again subjected to the action of the acid and analyzed: —

0.1561 gram of the oil gave 0.4847 gram CO_2, and 0.2127 gram H_2O.

C	84.67
H	15.14

The slight change in the percentages of carbon and hydrogen evidently shows the presence of a heavy body that is but slowly affected by the acid. This impurity cannot be mesitylene, since this hydrocarbon dissolves readily in the fuming acid. Another portion of the crude distillate was next vigorously agitated with a mixture of nitric and sulphuric acids, allowing the temperature to rise spontaneously nearly to 100°. As soon as the principal action ceased, the mixture cooled and an oily nitro body

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separated, more remaining in solution. After several crystallizations from alcohol, in which it is quite insoluble, the nitro derivative melted at 225°, near the melting point of trinitromesitylene. The hydrocarbon oil was separated from the acid and boiled several hours with tin and hydrochloric acid, which caused the yellow color to be absorbed by the acid solution, and a small amount of a heavy oil separated, insoluble in the acid, evidently a product of the vigorous reduction. The crude distillate lost 20 per cent in weight by this purification. The oil remaining after the reduction, when shaken with fuming sulphuric acid, washed, and dried, gave only the characteristic odor of the petroleum hydrocarbons. Upon analysis it gave the following results: —

0.1455 gram of the oil gave 0.4517 gram CO_2, and 0.1980 gram H_2O.

	Calculated for $C_{10}H_{22}$	Found.
C	84.51	84.67
H	15.49	15.12

While these results point clearly to the composition C_nH_{2n+2} for the principal hydrocarbon with this boiling point, they also suggest, as has already been mentioned, a constituent of Canadian oil so inert toward reagents that it cannot be removed by ordinary means. No doubt the difficulty is increased by the great dilution of this impurity in the larger body of the decane. In its behavior toward reagents, dekanaphtene is suggested. Whatever may be the composition of this body, it is doubtless present in largest quantity in Canadian petroleum, a smaller amount in Ohio oil, and a still smaller proportion in Pennsylvania oil. But even in the Canadian oil, the proportion is evidently very small.

The formula of the principal constituent at 163° found still further support in a determination of its molecular weight by the method of Beckmann, in which Mr. Hudson obtained 142; the formula $C_{10}H_{22}$ requires 142.

The purified distillate 160°–161°, Canadian petroleum, behaved toward chlorine precisely like the corresponding distillates from Ohio and Pennsylvania oils. 17 grams absorbed 4 grams chlorine, and was then fractioned *in vacuo*. About 1 c.c. was obtained after five distillations at 200°–204° atmospheric pressure, without decomposition, and it gave by analysis the composition required for $C_{10}H_{21}Cl$: —

I. 0.1922 gram of the substance gave 0.1536 gram AgCl.

II. 0.1873 gram of the substance gave 0.4710 gram CO_2, and 0.207 gram H_2O.

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	Calculated for $C_{10}H_{21}Cl$.	Found. I.	II.
C	68.00		68.58
H	11.90		12.30
Cl	20.11	19.77	

The quantity of this monochlor decane was too limited to permit of further determinations, as were also the higher portions for the separation of a dichlor derivative sufficiently pure for analysis.

Having at hand a small quantity of the distillate 162°, Berea Grit petroleum, it seemed of interest to ascertain whether it would form a chlorine derivative similar or identical with those of the oils now under examination. 30 grams of the oil absorbed 8 grams of chlorine in forty-five minutes, and when the product was fractioned it gave a small quantity at 120°–130° with the composition required for $C_{10}H_{21}Cl$: —

I. 0.1931 gram of the substance gave 0.1564 gram AgCl.

II. 0.1821 gram of the substance gave 0.4486 gram CO_2, and 0.1871 gram H_2O.

	Calculated for $C_{10}H_{21}Cl$.	Found I.	II.
C	68.00		67.19
H	11.90		11.41
Cl	20.11	20.04	

The formation of this chlordecane confirms the results published in a former paper* of this series, showing a hydrocarbon $C_{10}H_{22}$ in Berea Grit petroleum with the boiling point 162°.

Decane, 173°–174°.

Above 163° (730 mm.) the absence of single bodies was indicated by the small amounts of distillates to 168°, where the single degree fractions began to increase in quantity. Between this point and 173° nearly 500 grams collected, the greater portion at 169°–171°, which could not be brought closer together without further purification. After drying over sodium, analysis of this distillate gave the following percentages of carbon and hydrogen: —

0.1640 gram of the oil gave 0.5151 gram CO_2, and 2083 gram H_2O.

C	85.66
H	14.11

* Amer. Chem. Journ., XVIII. 1.

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A determination of the specific gravity of this distillate at 20° gave 0.7770, a value somewhat higher than the specific gravity of the corresponding Ohio distillate. For the removal of the aromatic hydrocarbons to determine the boiling point of the principal constituent, all the fractions 168°–173° were agitated and warmed with fuming sulphuric acid, washed, dried, and the distillation continued until after a few repetitions the fractions came together at 169°–170° (730 mm.), or under 760 mm., and with the mercury column all in the vapor at 173°–174°. By this treatment the specific gravity was reduced to 0.7614, and the percentages of carbon and hydrogen changed in a proportionate degree: —

I. 0.1545 gram of the oil gave 0.4810 gram CO_2, and 0.2091 gram H_2O.

II. 0.1446 gram of the oil gave 0.4485 gram CO_2, and 0.1946 gram H_2O.

III. 0.1678 gram of the oil gave 0.5204 gram CO_2, and 0.2246 gram H_2O.

	Calculated for		Found.		
	$C_{10}H_{20}$	$C_{10}H_{22}$.	I.	II.	III.
C	85.71	84.51	84.90	84.59	84.57
H	14.29	15.49	15.04	14.96	14.89

Although these results indicate the removal of a large portion of the aromatic hydrocarbon, and analyses II. and III. were made of different specimens with the action of the acid continued several hours, it is evident that the less hydrogenized body was not even then entirely removed. In further confirmation of the presence still of this constituent, one of the oils treated with the fuming acid was shaken with a mixture of nitric and sulphuric acids. The solution became warm and an oily nitro product separated above the acid. Since Markownikoff preferred purification of the Russian oil with sulphuric acid to avoid the formation of objectionable nitro products, it was inferred that this acid should remove completely the aromatic bodies. But in our experience with American oils, complete purification cannot be reached with the fuming acid alone. At first we relied on decomposition of the nitro product with sodium; but this required long digestions several times repeated, and in Canadian distillates the residual hydrocarbon which contained the nitrogen could not always be entirely removed, as shown by analysis of a portion of crude distillate purified in this manner: —

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I. 0.1656 gram of the oil gave 0.5156 gram CO_2, and 0.2241 gram H_2O.

II. 0.1736 gram of the oil gave 0.5419 gram CO_2, and 0.2345 gram H_2O.

	Calculated for $C_{10}H_{22}$.	Found. I.	Found. II.
C	84.51	84.90	85.13
H	15.49	15.04	15.01

The specific gravity of this distillate was found to be 0.7618, the same as that purified by fuming sulphuric acid. Another portion of the same crude distillate was treated with the mixture of concentrated nitric and sulphuric acids. The great heat developed was controlled by cooling, and finally the heavy nitro product collected above the acid. 25 grams of the crude distillate lost 9 grams in the formation of the nitro product, equivalent to 36 per cent. In another experiment 25 grams of the crude distillate treated with fuming sulphuric acid lost 6 grams, or 24 per cent. The oil remaining after the first experiment was again treated with the mixture of acids, which caused further separation of the nitro product. For the removal of the nitro compound, the oil was boiled during several hours with tin and hydrochloric acid. The reduction was very slow and a red oil separated, leaving the upper layer colorless. The latter was then agitated with concentrated sulphuric acid, washed, dried, and analyzed: —

0.1449 gram of the oil gave 0.4494 gram CO_2, and 0.2051 gram H_2O.

	Calculated for $C_{10}H_{22}$.	Found.
C	84.51	84.57
H	15.49	15.73

The oily nitro derivative of the aromatic hydrocarbon deposited crystals on standing, which after recrystallization from hot alcohol, in which it was very sparingly soluble, melted at 169°. The quantity obtained was insufficient for analysis.

The specific gravity of the oil purified as described above was 0.7601, and, as shown by the vigorous means of purification employed, it cannot easily be reduced, although it is materially larger than the specific gravity of the decane 173° separated from Ohio oil, 0.7513, and of the decane from Pennsylvania oil, 0.7467. But the analyses show that the principal constituent is a hydrocarbon of the series C_nH_{2n+2}. The molecular weight of this hydrocarbon, determined by the Beckmann method, gave Mr. Hudson 144; required by the formula $C_{10}H_{22}$, 142.

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In forming the chlorine derivative of this fraction, 35 grams was exposed to the action of chlorine until it had increased in weight 12 grams. After ten distillations *in vacuo*, 5 c.c. were collected at 135°–138°, which upon analysis gave values required for $C_{10}H_{21}Cl$: —

I. 0.1950 of the oil gave 0.4835 gram CO_2, and 0.2143 gram H_2O.
II. 0.2083 gram of the oil gave 0.1672 gram AgCl.

	Calculated for $C_{10}H_{21}Cl$.	Found. I.	II.
C	68.00	67.69	
H	11.90	12.21	
Cl	20.11		19.86

The crude distillate having been used in the preparation of the chlorine derivatives, the action on the eyes during distillation was severe, doubtless due to substitution in the side chain of the aromatic hydrocarbons contained in the unpurified oil.

In distilling the higher fractions, 5 c.c. collected at 170°–180° that distilled under atmospheric pressure at 205°–210°. It was shown by analysis to have the composition required for $C_{10}H_{20}Cl_2$: —

I. 0.2405 gram of the substance gave 0.3214 gram AgCl.
II. 0.2057 gram of the substance gave 0.4352 gram CO_2, and 0.1772 gram H_2O.

	Calculated for $C_{10}H_{20}Cl_2$.	Found. I.	II.
C	56.87		57.69
H	9.48		9.57
Cl	33.65	33.02	

The specific gravity of this dichlordecane was found to be 1.0484. A determination of its molecular weight by the Beckmann method gave 207; the formula $C_{10}H_{20}Cl_2$ requires 211.

Hydrocarbon, $C_{11}H_{22}$.

Above 173°, the absence of a definite product was shown by the small amount of the distillates to 188°. Especial attention was given to the fractions in the vicinity of 180° with reference to the possibility of a naphtene, since the naphtene $C_{12}H_{24}$ boiling at 180°–185° was separated by Markownikoff from Russian oil, and Pelouze and Cahours found a hydrocarbon C_nH_{2n+2} boiling at 180°–182° in American (Canadian?) petroleum. But the very small amounts collected within these limits

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precluded the presence of either of these bodies in any appreciable quantities in Canadian petroleum. The portions distilling between 188° and 200° were gradually brought together at 189°–191°. A portion of the crude distillate was treated with fuming sulphuric acid and still further fractioned until for the most part it came together at 196°–197° under 760 mm., and with the mercury column all in the vapor. In drying the crude distillate with sodium for analysis the usual reddish flocculent precipitate separated, which doubtless changed somewhat the composition of the oil: —

0.1565 gram of the oil gave 0.4921 gram CO_2, and 0.2041 gram H_2O.

C	85.74
H	14.49

This oil gave 0.7889 as its specific gravity at 20°, and after treatment with ordinary sulphuric acid 0.7856, the slight difference indicating that this acid has very little action in the cold on this distillate, although the acid was considerably blackened, and sulphurous acid was observed. Another portion of the crude distillate with fuming sulphuric acid developed no heat, and when warmed on the steam bath the acid was only slightly colored. After this treatment the specific gravity was 0.7832, nearly the same as before. A third portion of the original distillate was agitated with a mixture of concentrated nitric and sulphuric acids. Very little heat was developed, and the mixture was then warmed on the steam bath. A small amount of nitro product separated as an oil, which crystallized on standing. After crystallization from alcohol, the nitro derivative melted at 150°–154°, near the melting point of dinitroisodurol, 156°. After heating a long time with sodium, until there was no further action, the specific gravity was found to be 0.7785. The purified oil was submitted again to the same treatment, when its specific gravity was 0.7758. Still another treatment of the same oil with the mixture of acids and boiling with sodium, also boiling with tin and hydrochloric acid, and agitating with fuming sulphuric acid, reduced the specific gravity only to 0.7729. Analysis I. was made of the oil after the first treatment with the mixture of acids and sodium, and analysis II. of the oil after the third treatment: —

I. 0.1562 gram of the oil gave 0.4901 gram CO_2, and 0.2051 gram H_2O.

II. 0.1628 gram of the oil gave 0.5093 gram CO_2, and 0.2095 gram H_2O.

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	Calculated for		Found.	
	$C_{11}H_{24}$.	$C_{11}H_{22}$.	I.	II.
C	84.70	85.71	85.57	85.33
H	15.30	14.29	14.59	14.30

A determination of the molecular weight by the method of Beckmann gave 154; the formula $C_{11}H_{22}$ requires 154.

These results indicate the series C_nH_{2n}, and that the series C_nH_{2n-2} has ceased to represent the principal composition of Canadian petroleum at the boiling point 196°. But with reference to the series of hydrocarbons that are now recognized as constituting the main body of petroleum, it is not easy to classify this hydrocarbon. It is certainly not an unsaturated member of the ethylene series because it lacks additive power for the halogens, fuming sulphuric acid, etc. Its specific gravity is much less than that of the naphtene that Markownikoff and Oglobine separated at 196°–197° from the Russian oil, 0.8010 at 20°. But it is interesting to observe that the specific gravity of this hydrocarbon is practically the same as Pelouze and Cahours found in the hydrocarbon separated by them at 196°–200° from American petroleum, and which yielded them analytical values, as has already been explained, page 134, corresponding closely to the formula $C_{12}H_{26}$. Since the specific gravity of Pelouze and Cahours is so much larger than that of the crude distillate from Pennsylvania petroleum, 0.7673, it is difficult to escape the conviction that their distillates were prepared from Canadian petroleum, especially since they allude to an examination of oil from Canada, although the source of the particular oil from which were separated the individual hydrocarbons which they described is not evident from their statements.

In studying the constituents of Pennsylvania oil, it has already been shown that chlorine acts less readily on the principal hydrocarbons than on other constituents. Since this difference on the action of chlorine seemed to afford a means of ascertaining whether Canadian distillates contain any of the series C_nH_{2n+2}, a small quantity, 16 grams, of the distillate 189°–190° purified with fuming sulphuric acid remaining after the examination already described, was exposed to the action of chlorine until three grams was absorbed, and the product was fractioned *in vacuo* until a small portion, six grams, distilled at 189°–190° atmospheric pressure. This fraction was boiled with sodium to remove, so far as possible, any chlorine derivative remaining, shaken with sulphuric acid, and again distilled. There was finally obtained about three grams that gave percentages of carbon and hydrogen agreeing fairly well for $C_{11}H_{24}$.

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The low values are due to a small amount of chlorine that was not entirely removed even by the treatment with sodium: —

0.1558 gram of the oil gave 0.4803 gram CO_2, and 0.2115 gram H_2O.

	Calculated for $C_{11}H_{24}$.	Found.
C	84.70	84.09
H	15.30	15.09

In the formation of chlorine derivatives from the purified fraction 196°, Canadian petroleum, 25 grams absorbed 7 grams chlorine. After five distillations *in vacuo*, 3 c.c. collected at 145°–150°, which distilled at 220°–228° atmospheric pressure, and by analysis gave values required for $C_{11}H_{21}Cl$: —

I. 0.2378 gram of the substance gave 0.1747 gram AgCl.

II. 0.2005 gram of the oil gave 0.5105 gram CO_2, and 0.2097 gram H_2O.

	Calculated for $C_{11}H_{23}Cl$.	Found. I.	Found. II.
C	70.03		69.44
H	11.14		11.62
Cl	18.83	18.18	

A determination of the specific gravity of the monochloride at 20° gave 0.8882. With the small quantity of the higher distillates, it was not possible to separate a dichlor derivative in any degree of purity.

The small amount of the monochloride evidently precluded the possibility of ascertaining with any precision the true boiling point, and the analysis is chiefly of value in determining the number of carbon atoms in the molecule. The number of carbon atoms received still further confirmation in a determination of the molecular weight by the Beckman method, which gave 187; the formula $C_{11}H_{21}Cl$ requires 188.5.

Hydrocarbon, $C_{12}H_{24}$.

Above 195° (730 mm.) the distillates were small in quantity to 208°, but between 208° and 212° about 300 grams collected, for the most part at 208°–210°. The specific gravity of the crude distillate was found to be 0.7947, and analysis gave the following percentages of carbon and hydrogen: —

0.1554 gram of the oil gave 0.4878 gram CO_2, and 0.1982 gram H_2O.

	Required for C_nH_{2n}.	Found.
C	85.71	85.57
H	14.29	14.18

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In order to collect this distillate more closely, a portion of the crude oil was treated with fuming sulphuric acid, washed, dried, and the distillation continued. 37 grams of the oil gave 27 grams after purification. After several distillations it collected at 212°–214° under 745 mm., and with the mercury all within the vapor. Two determinations of specific gravity at 20° gave (I.) 0.7851, and (II.) 0.7857. The carbon and hydrogen were also determined: —

0.1586 gram of the oil gave 0.4960 gram CO_2, and 0.2105 gram H_2O.

	Calculated for $C_{12}H_{24}$.	Found. I.
C	85.71	85.27
H	14.29	14.74

These values point to the composition C_nH_{2n} for this constituent of the Canadian oil. In further evidence as to the correctness of this result, another portion of the crude distillate was shaken with a mixture of concentrated nitric and sulphuric acids, the intense heat at first generated controlled, and after the principal action had ceased the solution was kept warm for some time on the steam bath. An oily nitro product collected above the acid in considerable quantity, but it was not further examined. The hydrocarbon remaining was then agitated with concentrated sulphuric acid, washed with caustic soda, which removed much more of the nitro product from the oil, then with water, and boiled for some time with tin and hydrochloric acid.

The oil remaining was then washed, dried, and warmed during several hours with fuming sulphuric acid, which produced little change, and boiled with sodium. After this purification, analysis still gave values required for a hydrocarbon C_nH_{2n}.

I. 0.1383 gram of the oil gave 0.4332 gram CO_2, and 0.1849 gram H_2O.
II. 0.1406 gram of the oil gave 0.1856 gram H_2O.

	Calculated for $C_{12}H_{24}$.	Found. I.	II.
C	85.71	85.41	Lost.
H	14.29	14.86	14.68

In forming the chlorine derivatives of this hydrocarbon, 26.5 grams of the fraction 214°–216° was allowed to absorb chlorine until the weight had increased 9.5 grams, and the product was fractioned eight times *in vacuo;* 5 c.c. collected at 160°–170°, which gave on analysis the percentage composition required for $C_{12}H_{23}Cl$.

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I. 0.2059 gram of the substance gave 0.1515 gram AgCl.

II. 0.2064 gram of the substance gave 0.5357 gram CO_2, and 0.2128 gram H_2O.

	Calculated for $C_{12}H_{23}Cl$.	Found. I.	II.
C	71.06		70.79
H	11.30		11.46
Cl	17.53	18.20	

The specific gravity of this chlorine derivative determined at 20° was found to be 0.8960. The small quantity of distillate collected within higher limits did not permit of the separation of a dichlor derivative in a pure condition. A chlorine determination gave 27.21; required for $C_{12}H_{22}Cl_2$, 29.95. It formed a thick viscous oil that could scarcely be distilled even *in vacuo* without decomposition. At a temperature slightly higher than where this product was collected the distillate was largely decomposed.

The series having been determined by these numbers, the number of carbon atoms was demonstrated by the molecular weight, which was found by the Beckmann method to be 172; the formula $C_{12}H_{24}$ requires 168.

What has been said as to the probability that Pelouze and Cahours operated on Canadian petroleum receives further support in comparing their results on the hydrocarbon they separated boiling at 216°–218° with those described above, although certain important differences appear between their results and mine.

The specific gravity assigned by them to the hydrocarbon 216°–218° was 0.796 at 20°, which is practically the same as the specific gravity of my crude distillate, 0.7947, given above. But their description of the properties of this distillate are not in accordance with my observations. Referring to the action of reagents on their product, they state: "Le brome, l'acide azotique fumant, l'acide sulfurique fumant, ainsi que le mélange de ces deux acides se comportent à son égard comme avec le composé précédent." And after stating, in the description of the preceding compound, that it is not attacked in the cold by bromine, fuming nitric acid, sulphuric acid at the maximum of concentration with nitric acid, nor by fuming sulphuric acid, they state: "Le mélange des acides azotique et sulfurique agit sur le carbure lorsqu'on maintient ces corps pendant quelque temps en ébullition." That this observation does not represent correctly the behavior of this distillate from Pennsylvania nor Ohio, nor Canadian petroleum, has been clearly shown by experiments described in this paper. It is especially inapplicable to the Canadian distillate,

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since this oil with a mixture of ordinary concentrated nitric and sulphuric acids, on shaking, immediately develops sufficient heat to raise the temperature to vigorous ebullition of the acid mixture, and to destroy a large portion of the hydrocarbon. In all these experiments the initial reaction had to be controlled by cooling.

Concerning the number of carbon atoms in the hydrocarbon I have separated at this point, it seems to be well established by the molecular weight, $C_{12}H_{24}$, and by the composition of the monochlor derivative, $C_{12}H_{23}Cl$. Yet in a product with a specific gravity much higher than this purified hydrocarbon, Pelouze and Cahours obtained numbers by analysis, as shown above, page 141, closely supporting the formula $C_{13}H_{26}$, and from the hydrocarbon a chlorine derivative, $C_{13}H_{27}Cl$, also supported by analytical values closely corresponding to the theoretical composition required for this formula.

Summary of Results.

1. Pennsylvania petroleum is composed chiefly between 150° and 220° of decane, boiling point 163°–164°; decane, boiling point 173°–174°, probably normal decane; hendecane, boiling point 196°–197°; and dodecane, boiling point 214°–216°. It contains also in smaller proportions the series of aromatic hydrocarbons boiling within these limits. Allusion has already been made to mesitylene, cumol, pseudocumol, cymol, isocymol, durol, isodurol, and no doubt others could be identified with sufficient quantities of the petroleum distillates.

2. The composition of Ohio Trenton Limestone petroleum within the same limits is represented by the same members of the series C_nH_{2n+2}, and the higher specific gravity of these distillates is caused by a larger proportion of aromatic hydrocarbons.

3. The constituents of Canadian Corniferous limestone petroleum from Petrolia, within these limits of temperature, are the same at 163° and 173°. But the hydrocarbons collecting at 196° and 214° have the composition represented by the series C_nH_{2n}. Probably a better knowledge of these higher distillates will be gained when the true composition of American petroleum above 220° has been ascertained. The proportion of aromatic hydrocarbons is greater in Canadian than in Ohio petroleum. There are indications in all these petroleums that the heavier constituents include other bodies than the aromatic hydrocarbons, which will require for their identification the manipulation of large quantities of distillates.

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General Conclusions.

The results described in this paper make it clear that no conclusions can be arrived at concerning the composition of the principal constituents of American petroleum between 151° and 216° without separating from these bodies the various impurities with which they are contaminated in the crude distillates. However far fractional distillation may be carried, it is impossible to effect a separation of those bodies whose boiling points do not differ by more than a few degrees. But fortunately the principal constituents of petroleum are not affected by reagents under conditions which allow the removal of the contaminating bodies. While the statement of Pelouze and Cahours that the portions of American petroleum under consideration are not affected by nitric acid nor by fuming sulphuric acid is not supported by the behavior of distillates used by me in this examination, it is true that the principal constituents are not acted upon by those reagents under conditions that permit of purification. A casual examination of the literature of Pennsylvania petroleum is sufficient to reveal the uncertainty and confusion in statements concerning the composition of the portions with higher boiling points. The principal constituents have more commonly been referred to the series C_nH_{2n+2}, as suggested by Pelouze and Cahours, who included in this series all the petroleum hydrocarbons, even the least volatile oils and paraffine, although on the basis of Warren's investigations allusions have been made to the unsaturated olefine hydrocarbons C_nH_{2n} as constituting the main body of Pennsylvania petroleum above 150°, and the belief has been expressed that the naphtene series C_nH_{2n} should best explain Warren's results. As already stated, above 150° Pelouze and Cahours separated distillates at 162°, 182°, 196°–200°, and 216°–218°, which, with no especial purification, gave analytical data corresponding closely with the theoretical values for the series C_nH_{2n+2}. That there are marked differences in the specific gravity of crude and refined distillates appears in the purification of all distillates described in this paper, and it is no easy task to purify the crude distillates so that they shall yield satisfactory analytical data. As shown in the following table, the specific gravity determinations by Pelouze and Cahours in the products they analyzed are essentially different from those in Pennsylvania distillates herein presented. The percentages of carbon and hydrogen required for the series C_nH_{2n+2} were obtained in fractions whose specific gravity was even higher than our crude distillates, which gave values closely agreeing with the series C_nH_{2n}. This difference in specific gravity can only be explained

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by assuming, which is evidently true, that Pelouze and Cahours overlooked the aromatic hydrocarbons. It does not appear in their reference to American petroleum whether they really operated on distillates from Pennsylvania oil; but, on the other hand, their specific gravity determinations are not widely different from those of distillates from Canadian oil to which occasional reference is made in their publications.

PENNSYLVANIA PETROLEUM.

Fraction.			Specific Gravity.		
C. F. M.		P. & C.	C. F. M.	P. & C.	Series.
Unpurified.	Purified.				
163°–164°			0.7684 (20°)		C_nH_{2n}
	163°–164°		0.7479 (20°)		C_nH_{2n+2}
		162°		0.757 (15°)	C_nH_{2n+2}
196°–197°			0.7673 (20°)		C_nH_{2n}
	196°–197°		0.7581 (20°)		C_nH_{2n+2}
		196°–200°		0.7780	C_nH_{2n+2}
214°–216°			0.7745 (20°)		C_nH_{2n}
	214°–216°		0.7684 (20°)		C_nH_{2n+2}
		216°–218°		0.796	C_nH_{2n+2}

CANADIAN PETROLEUM.

Fraction Unpurified.	Fraction Purified.	C. F. M.
163°–164°		0.7785
	163°–164°	0.7582
196°–197°		0.7889
	196°–197°	0.7729
214°–216°		0.7947
	214°–216°	0.7851

If the results of Pelouze and Cahours were really obtained in distillates from Canadian petroleum, as seems probable, especially since Pennsylvania distillates do not yield such high values, the specific gravity determinations in their lower distillates agree fairly well with mine in the purified Canadian hydrocarbons.

The results of Warren, on the other hand, are consistent in giving numbers that account both in specific gravity and in percentage composition for the complex mixture that crude petroleum distillates are known to be. While Warren made no attempts to purify his distillates, they were obtained in a course of fractional separations far exceeding in efficiency those of other experimenters. It is interesting to observe in the following

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table how closely the distillates from Pennsylvania petroleum analyzed by Warren resemble in specific gravity the unpurified distillates described in this paper.

Fraction. Unpurified.	Fraction. Purified.	Specific Gravity. Mabery.	Warren	Series.
163°–164°		0.7674 (20°)		C_nH_{2n}
173°.5		0.7502 (20°)		C_nH_{2n}
	173°.5	0.7445 (20°)		C_nH_{2n+2}
175°			0.7598 (15°)	C_nH_{2n}
196°		0.7673 (20°)		C_nH_{2n}
	196°	0.7581 (20°)		C_nH_{2n+2}
196°–197°			0.7721 (15°)	C_nH_{2n}
216°		0.7745 (20°)		C_nH_{2n}
	216°	0.7684 (20°)		C_nH_{2n+2}
214°–216°			0.7804 (15°)	C_nH_{2n}

Warren found no single body at 162° ; his other hydrocarbons correspond in boiling points with those described in this paper. The series C_nH_{2n} of Warren, with a series of the same numerical composition in Russian oil, led to the suggestion that the naphtenes might form an essential part of Pennsylvania oil. This belief was encouraged by statements that found their way into works on petroleum, that Markownikoff discovered the naphtenes also in Pennsylvania oil. The statement that Markownikoff investigated Pennsylvania petroleum is indeed erroneous,* and a closer study shows that the naphtenes cannot be contained in Pennsylvania petroleum in any considerable quantity on account of their higher specific gravity as already shown (page 143):

Fraction. Unpurified.	Fraction. Purified.	Specific Gravity. Mabery.	Markownikoff.	Series.
163°–164°		0.7684		C_nH_{2n}
	163°–164°	0.7479		C_nH_{2n+2}
	160°–162°		0.795 (0°)	C_nH_{2n}
	180°–185°		0.8119 (0°)	C_nH_{2n}
196°–197°		0.7673		C_nH_{2n}
	196°–197°	0.7581		C_nH_{2n+2}
	196°		0.8055 (14°)	C_nH_{2n}
214°–216°		0.7745		C_nH_{2n}
	214°–216°	0.7684		C_nH_{2n+2}

* In a private communication, I am informed by Professor Markownikoff that he has not included Pennsylvania petroleum in his investigations.

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Even the mixtures that the crude Pennsylvania distillates have proved to be are much lower in specific gravity than those with the same boiling points from Russian oil. After purification, the Pennsylvania distillates unquestionably have the composition of the series C_nH_{2n+2}.

Allusion has been made to the great difficulty in removing entirely the constituent with less hydrogen from the distillates prepared for analysis, and also to the fact that, even after the most thorough purification, the specific gravity of the purified distillate is appreciably higher than that of the hydrocarbon with the same boiling point prepared by synthetic methods. These facts may indicate the presence in small quantity of naphtenes which are acted on only very slowly by reagents, especially when largely diluted in the main body of the principal constituent.

Structure of the Petroleum Hydrocarbons, 160°–216°.

In comparing the petroleum hydrocarbons with the corresponding bodies synthetically prepared, it is but fair to state that the literature of the latter is not altogether satisfactory. The properties of normal decane as it was prepared by Lachowicz,* by the action of sodium on a mixture of normal octyl bromide and ethyl iodide, and also by Krafft,† by heating caprinic acid with a mixture of hydriodic acid and phosphoric pentachloride, seem to define the corresponding petroleum hydrocarbon as the normal compound.

The boiling point of the hydrocarbon synthetically prepared is 173° under 760 mm., and its specific gravity 0.7456 at 0°. The boiling point assigned by me to petroleum decane is 173°.5, and its specific gravity at 20° is (from Pennsylvania petroleum) 0.7486. Evidently the decane obtained by Thorp and Young by heating solid paraffine, boiling at 166°–168°, specific gravity 0.7394 at 13°.5, is an impure normal hydrocarbon.

A decane has been obtained by several methods, boiling at various temperatures between 157° and 162°. Active diamyl boiling at 159°–162°, specific gravity 0.7463 at 22°, with a high dextro rotatory power, was obtained by Just, on treating active amyl iodide with sodium. But the petroleum decane has not the same form, since it shows no influence on polarized light. The latter has with greater probability the same form as diisoamyl, obtained by Wurtz on heating isoamyl iodide with sodium. The boiling point of this secondary decane is given by Wurtz as 158°, with no mention of barometric tension, and specific gravity as 0.7413.

* Ann. Chem. Pharm., CCXX. 179.

† Ber. der deutsch. chem. Gesellsch., XV. 1695.

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Petroleum decane boils at 163°, and its specific gravity at 20° is 0.7479. In a similar reaction using amyl bromide, Grimshaw * obtained a decane boiling at 168°, under 751 mm. Either the normal bromide must have been used in this reaction giving normal decane, or the boiling point of the product is too high.

Normal hendecane (or undecane) was prepared by Krafft † from the aldehyde rautenol by the same reaction that he used for decane. Its boiling point is given as 194°.5 under 760 mm., and the specific gravity as 0.7411 at 20°. Since the boiling point, 196°–197°, and specific gravity, 0.7581, of petroleum hendecane and the formula of this body, $C_{11}H_{24}$, determined by its molecular weight, correspond so closely to normal hendecane, it has doubtless the same form. As already explained, the higher specific gravity may be due to a small proportion of a naphtene.

The formula $C_{12}H_{26}$, which represents the petroleum hydrocarbon boiling at 214°–216°, is supported by that of normal dodecane which Krafft ‡ obtained by the reduction of laurinic acid. Normal dodecane boils at 214°.5, atmospheric pressure, and its specific gravity at 20° is 0.7511. The specific gravity of petroleum dodecane was found to be 0.7729.

Relation between Specific Gravity and Chemical Composition of Petroleum Distillates.

One interesting result of the examinations described in this paper, and other papers of this series, is the relation between the chemical composition of the individual hydrocarbons and the density of the crude oils from which they were prepared. Pennsylvania petroleum with the lowest specific gravity, 0.80–0.82, is composed below 220° of the hydrocarbons C_nH_{2n+2}. Ohio oil, next higher in the scale of specific gravity, 0.82–0.85, still contains below 220°, as its principal constituents, hydrocarbons of the same series. As the density increases, in the Canadian oil, specific gravity 0.85–0.88, the series C_nH_{2n+2} represents the principal constituents up to and including decane, boiling point 173°, the higher members having the composition C_nH_{2n}. But oils with higher specific gravity, such as a South American petroleum, specific gravity 0.9480, described in another paper of this series, contain only hydrocarbons of the series C_nH_{2n}, and in Caucasus petroleum, specific gravity 0.88, Markownikoff and Oglobine found as the principal constituents the naphtenes, series C_nH_{2n}.

* Ber. der deutsch. chem. Gesellsch., X. 1602.
† Ibid., X. 1697.
‡ *Loc. cit.*, 1698.

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Action of Sulphuric Acid on Petroleum Distillates.

Since the beginning of the petroleum industry, the sole method of refining has depended on agitation with sulphuric acid; yet, notwithstanding the large quantities of material that sulphuric acid removes, as shown by the immense sludge heaps in the vicinity of the refineries, the refiner has not the slightest notion as to what the acid accomplishes beyond his principal object, which is to prepare acceptable products for the market. Neither has any scientific study been made of this problem, at least in American petroleum, so far as revealed by published statements, but that this is an interesting as well as a difficult subject appears from results described in several papers of this series. That ordinary concentrated sulphuric acid has some effect on the density of petroleum distillates is evident from numerous experiments described in this paper. But without independent evidence, it cannot be determined just what constituents are affected by the acid. That some of these constituents, present in small quantity, are unstable and easily acted on by reagents is evident. The refiner must avoid an elevation of temperature during treatment with the acid, otherwise a color appears in the oil that is difficult to remove without redistillation. Evidently an increase in temperature permits of troublesome chemical changes between the acid and the oil, with the formation of products that remain in solution. The skilful refiner is also careful to remove the acid by washing before adding caustic soda to avoid an objectionable color.

In studying the action of sulphuric acid on different distillates from the Russian oil, Markownikoff and Oglobine * attributed the influence of the acid mainly to its action on the unsaturated hydrocarbons and the oxygen compounds. Having separated a series of unsaturated hydrocarbons from Canadian petroleum, (Mabery and Quayle, unpublished results,) and ascertained the presence of the same bodies in Ohio petroleum,† on account of their unstable character and the ease with which they polymerize alone, or more readily when in combination with sulphuric acid, it is evident that one important office of the acid is the removal of these compounds. With reference to the oxygen compounds in American petroleum, they seem to collect for the most part at least in the distillates above 225°. In the composition of their unpurified distillates, Markownikoff and Oglobine found a considerable difference between the total percentages of carbon and hydrogen and 100 per cent, which they assigned to oxygen. In analysis of unpurified distillates described in this paper, the

* Ann. Chim. Phys., (6.), II. 404. † Proc. Amer. Acad., XVII. 218.

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total percentages of carbon and hydrogen in most instances have approached 100 per cent to within the limit of the error of analysis, although it is true that these distillates were subjected to close fractional distillation within 1°, while those of Markownikoff and Oglobine were distilled only a few times within limits of 5°. In all the distillations of Pennsylvania, Ohio, and Canadian petroleum, a slight coloration of the still residue after a long series has been observed, which may be due to a small amount of oxygen compounds.

On standing with metallic sodium, all the unpurified distillates described in this paper deposit flocculent precipitates, more or less colored, which are evidently products of decomposition. This cannot be due to the action on the principal hydrocarbon, since when purified such action by sodium is not observed. Neither should the aromatic hydrocarbons behave in this manner toward sodium. These precipitates must be formed from the oxygen or the nitrogen compounds in the oils, probably from the former. They cannot be due to decomposition of sulphur compounds, since Pennsylvania oil contains only a very small percentage of sulphur, and the other distillates were all treated with alcoholic mercuric chloride. It is quite probable that ordinary sulphuric acid combines to a certain extent with some of the aromatic hydrocarbons. A more extended study of the action of sulphuric acid on a larger scale as in refining, would doubtless be interesting and profitable.

Concerning the action of fuming sulphuric acid, no further explanation is necessary than has been given in connection with the experiments which describe its behavior toward these petroleum distillates.

So far as possible, all details of this work have been carried on under my immediate and constant personal supervision. For efficient aid I am indebted to the following gentlemen: Messrs C. A. Soch, private assistant, 1894–95; E. Davidson, private assistant, 1895–96; E. J. Hudson, molecular weight determinations, and other aid mainly in connection with the chlorine derivatives of the hydrocarbons; W. F. Priebe, who selected a portion of the work on the Pennsylvania distillates as the subject of a thesis for the degree of Bachelor of Science; and Messrs Giessen, Watson, Worstall, Piwonka, Shaw, and Walker, for faithful assistance in the routine work of distillation and combustions.

The work now in progress includes a study of the pentanes, hexanes, and heptanes in Pennsylvania petroleum, and the composition of the portions of Pennsylvania, Ohio, Canadian, Berea Grit, and South American petroleums between 216° and 350°.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF THE CASE SCHOOL OF APPLIED SCIENCE.

INVESTIGATIONS ON AMERICAN PETROLEUM.

By Charles F. Mabery.

XXVIII. — *REFRACTIVE POWER OF THE HYDROCARBONS AND CHLORINE DERIVATIVES DESCRIBED IN THE PRECEDING PAPER.*

By Charles F. Mabery and Edward J. Hudson.

Aid in the work described in this paper was given by the Academy from the C. M. Warren Fund for Chemical Research.

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XXVIII.— REFRACTIVE POWER OF THE HYDROCARBONS AND CHLORINE DERIVATIVES DESCRIBED IN THE PRECEDING PAPER.

By Charles F. Mabery and Edward J. Hudson.

Presented October 14, 1896.

Within recent years the refractive power of the hydrocarbons and their derivatives has received considerable attention by Brühl, Thomsen, and others, and attempts have been made to draw conclusions based on the relation between the index of refraction and density, to define structural relations. The experimental data have been obtained for the most part from bodies with a limited number of carbon atoms, in which the differences in refractive power are large. Independent of determinations bearing on theoretical considerations, the refractive power of oils and solutions has been accepted on practical grounds as a valuable property for recognition and for determining degrees of purity.

While it was not to be expected that the determination of refractive power in hydrocarbons with such a large number of carbon atoms as those contained in the higher portions of petroleum would be serviceable in ascertaining the structure of individual hydrocarbons, the wide differences in specific gravity between unpurified and purified distillates led us to believe that similar differences should be observed in refractive power. When subjected to experimental proof, these differences were easily verified.

The determinations of the angle of refraction were made in the latest form of Pulfrich refractometer, made by Carl Zeiss, Jena, and the calculations of the index of refraction by the formula $1 = \sqrt{N^2 - \sin^2 I}$, in which 1 represents the index of refraction, N the angle of the prism, and I the observed angle. The observations in this refractometer are rapidly made, and the calculations are much simplified by the use of a table arranged by

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Pulfrich * so that from the observed angle the index may read directly from the table.

In the following table giving the refractive power (the excess of the index of refraction over unity), after the numbers representing the refractive power of the distillates purified by a mixture of nitric and sulphuric acids, and with fuming sulphuric acid, the differences between the refractive power before purification and afterwards are given.

	Pennsylvania.		Ohio.		Canada.	
	163°.					
	Ref. Power,	Dif.	Ref. Power,	Dif.	Ref. Power,	Dif.
Unpurified distillate	.4241		.4248		.4276	
After treatment with HNO_3 and H_2SO_4	.4083	.0158	.4123	.0125	.4133	.0143
After treatment with $H_2S_2O_7$	.4146	.0095	.4113	.0135	.4137	.0139
	173°.5					
Unpurified distillate	.4163		.4239		.4245	
After treatment with HNO_3 and H_2SO_4	.4118	.0045	.4134	.0105	.4149	.0096
After treatment with $H_2S_2O_7$	.4093	.0070	.4118	.0121	.4138	.0107
	196°.					
Unpurified distillate	.4214		.4251		.4309	
After treatment with HNO_3 and H_2SO_4	.4158	.0056	.4214	.0037	.4219	.0090
After treatment with $H_2S_2O_7$	.4163	.0051	.4209	.0042	.4231	.0078
	216°.					
Unpurified distillate	.4249		.4280		.4289	
After treatment with HNO_3 and H_2SO_4	.4209	.0040	.4244	.0036	.4219	.0070
After treatment with $H_2S_2O_7$	.4209	.0040	.4241	.0039	.4212	.0077

Inspection of the columns in this table headed Refractive Power shows a gradual increase with the rise in boiling points, less regular in the un-

* Zeit. für Instrumentenkunde, 1888, p. 47.

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purified distillates, but more uniform after purification. A comparison of refractive power in the same distillates from all the oils reveals higher values in the Ohio and Canadian distillates than in those from Pennsylvania oil, analogous to the differences in specific gravity referred to in the preceding paper. In the unpurified distillate 163° from all sources, the influence of the large proportions of mesitylene is apparent.

In determining the refractive power of the monochlor and dichlor derivatives of the hydrocarbons between 160° and 216°, portions of the product were used whose composition was determined by analysis, as shown in the preceding paper. On account of the limited quantities purification was not carried as far as would have been desirable, although the proportion of other bodies was probably not sufficient to affect seriously the results. The differences in refractive power between the hydrocarbons and the monochlor derivatives, as well as those between the monochlor and dichlor derivatives are sufficient to demonstrate the influence of the chlorine atoms.

Monochlor derivatives: —				Pa.	Ohio.	Can.
Distillate						
125–130	($C_{10}H_{21}Cl$)	from	164°	.4424		
"	"	"	"		.4470	
130–140	($C_{10}H_{21}Cl$)	"	174°	.4445		
"	"	"	"		.4437	
145–150	($C_{11}H_{23}Cl$)	"	196°	.4433		
"	"	"	"		.4457	
"	"	"	"			.4461
140–145	($C_{12}H_{25}Cl$)	"	216°	.4456		
"	"	"	"			.4521

Dichlor derivatives: —						
Distillate.						
160–170	($C_{10}H_{20}Cl_2$)	from	164°	.4639		
"	"	"	"		.4770	
170–180	($C_{10}H_{20}Cl_2$)	"	174°	.4604		
"	"	"	"		.4640	
"	"	"	"			.4676
190–200	($C_{12}H_{24}Cl_2$)	"	216°		.4650	
"	"	"	"			.4747

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It seems peculiar that the hydrocarbon 216° Canadian petroleum which gives analytical values corresponding to the formula $C_{12}H_{24}$ should have the same boiling point as the corresponding constituent of Pennsylvania and Ohio oils, and that it should give a chlorine derivative with substantially the same boiling point. Probably a better understanding of this hydrocarbon will be gained in the study of the higher constituents, which is now in progress.

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INVESTIGATIONS ON AMERICAN PETROLEUM.

By Charles F. Mabery.

XXIX. — *ON THE COMPOSITION OF A SOUTH AMERICAN PETROLEUM.*

By Charles F. Mabery and Arthur S. Kittelberger.

Aid in the work described in this Paper was given by the Academy from the C. M. Warren Fund for Chemical Research.

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XXIX.—ON THE COMPOSITION OF A SOUTH AMERICAN PETROLEUM.

By Charles F. Mabery and Arthur S. Kittelberger.

Presented October 14, 1896.

It has long been known that large deposits of petroleum are to be found in various districts in South America, but beyond a limited use of the crude oil in lubrication, until recently no demand has been created for this petroleum. In the Argentine Republic are found heavy oils that deposit paraffine on distillation. In an examination of these oils by Engler and Ottin, hydrocarbons were found of the series C_nH_{2n+2} and C_nH_{2n}; they are said to yield a good illuminating oil. The oil fields of Peru and Bolivia have long been known, and large quantities of petroleum products are here obtained. The most promising oil fields hitherto in South America are those of Venezuela, and those deposits are receiving more attention in the preparation of commercial products.

The peculiar character of South American petroleum was brought to the attention of one of us (Mabery) in an examination which he was called upon to make by Mr. Horace M. Wilson of Cambridge, Mass., who collected a specimen of oil while prospecting along the Magdalena River in the United States of Colombia. A few miles from the river, in a rocky section of country, he discovered oil oozing up through a pool of water from a fissure in the rocks below. Oil was also observed escaping in bubbles through the water in a brook, where it formed a beautiful green layer three yards square. These sources and another within a range of two thousand feet were the only ones observed in a distance of fifteen miles. The geological formations in this section consisted of sandstones and shales tilted in nearly a horizontal position. At a distance of forty miles was a very large deposit of asphalt, hard and brittle like coal. About eighty gallons of this oil was collected at a rate of five gallons in twenty-four hours, of which the larger portion mixed with lard oil was used as a lubricator on car axles, for which it was found to be well adapted. Mr. Wilson brought home fifteen gallons of the oil, which was placed at our disposal for this examination.

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The crude oil gave as its specific gravity 0.9480 at 20°. It is a high sulphur oil, as shown by the following determinations: (I.), 0.70; (II.), 0.66 per cent. It absorbed bromine equivalent to 12.09 per cent. It also contains a large quantity of nitrogen, as shown by the following determinations: (I.), 0.321; (II.), 0.315 per cent. A determination of ash in the crude oil was made, in which 29.1360 grams of the oil was burned, and the ash ignited until all carbon was consumed. The residue weighed 0.313 gram, equivalent to 0.011 per cent, or the same amount of ash as is obtained from Ohio crude oil.* The ash contains much iron, as shown by its brown color.

Determinations of carbon and hydrogen in the crude oil gave the following results: —

	I.	II.
C	85.80	85.45
H	12.02	11.79

The crude oil was dark in color, thick and viscous, flowing very slowly at ordinary temperatures. In attempting to distil it under ordinary atmospheric pressure, nothing came over below 260°, and between this point and 345° it distilled in the following proportions, beginning with 290 c.c.: —

	—310°	310°–345°
	70 c.c.	70 c.c.
Specific gravity,	0.8749	0.8615
Bromine absorption,	8.46	34.96

As the great increase in bromine absorption shows, the distillate 310°–345° was badly cracked, and it had the very disagreeable odor of the worst decomposition products of high petroleum distillates. The lower fraction had only the natural odor of an undecomposed distillate. Nothing could be distilled above 345°, and the residue was completely coked. In respect to the instability of its least volatile portions, this oil differs from any North American oil that has come under my observation (Mabery). It was therefore evident that another method of distillation must be resorted to with any hope of separating without decomposition the principal constituents.

In subjecting the crude oil to distillation *in vacuo* under 50 mm., the first distillate came over at 100°, and below 250° the following weights

* Proc. Amer. Acad., XXXI. 20.

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were collected from 14.5 kilos, after the fourth distillation. It cannot be assumed that the absence of more volatile constituents was the result of evaporation by exposure on the surface of the water where the oil was found, since it was collected as soon as it appeared. No doubt such volatile portions as constitute gasoline on long exposure under such circumstances would be lost, but not constituents such as higher members of the series C_nH_{2n+2}, which do not appear in this oil.

	—130°	130°-135°	135°-140°	140°-150°	150°-155°	155°-160°	160°-165°
Grams	265	100	115	225	200	65	95
Sp. gr.					0.8706	0.8736	0.8747

	165°-170°	170°-175°	175°-180°	180°-185°	185°-190°	190°-195°
Grams	130	130	70	125	115	155
Sp. gr.	0.8784	0.8806	0.8846	0.8858	0.8867	0.8884

	195°-200°	200°-205°	205°-210°	210°-215°	215°-220°	220°-225°
Grams	140	165	95	110	100	145
Sp. gr.	0.8926	0.8947	0.8964	0.8989	0.9020	0.9045

	225°-230°	230°-235°	235°-240°	240°-245°	245°-250°	+250
Grams	145	150	100	93	75	130
Sp. gr.	0.9078	0.9113	0.9137			

Distillation of the fractions below 150° amounting to 700 grams was continued under atmospheric pressure, collecting within the limits of two degrees. After five distillations, ten in all from the beginning, heaps collected at 170°, 190°, and 212°, although in small quantities. The distillation could not be pushed too far on account of decomposition. The fraction 170°–172° (730 mm.) gave the following percentages of carbon and hydrogen: —

0.1456 grams of the oil gave 0.4556 gram CO_2, and 0.1864 gram H_2O.

	Calculated for $C_{10}H_{20}$.	Found.
C	85.71	85.33
H	14.29	14.23

Unfortunately there was not enough of this fraction to determine its specific gravity. A determination of sulphur gave 0.05 per cent. Its bromine absorption was found to be 3.5 per cent. No other heap appeared in the distillates below 190°. At 190°–192° more collected, evidently corresponding to a hydrocarbon boiling at 196°. A determination of the specific gravity of this distillate gave 0.8331. It absorbed bromine

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amounting to 3.56 per cent. A determination of sulphur gave 0.10 per cent. A combustion gave the following percentages of carbon and hydrogen: —

I. 0.1696 gram of the oil gave 0.5332 gram CO_2. The water was lost.
II. 0.1542 gram of the oil gave 0.4846 gram CO_2, and 0.1912 gram H_2O.

	Calculated for $C_{11}H_{22}$.	Found. I.	Found. II.
C	85.71	85.73	85.69
H	14.29		13.78

This distillate was treated with a mixture of nitric and sulphuric acids, then with fuming sulphuric acid. In the first treatment, a very small quantity of a nitro compound separated as on oil, showing a trace of an aromatic hydrocarbon. The fuming acid produced no appreciable action.

A determination of carbon and hydrogen in this product gave the following results: —

0.1618 gram of the oil gave 0.5019 gram CO_2, and 0.2087 gram H_2O.

	Calculated for $C_{11}H_{22}$.	Found.
C	85.71	85.47
H	14.29	14.33

A determination of the specific gravity of the oil after this treatment gave 0.8333. Besides the very small proportion of aromatic hydrocarbon C_nH_{2n-6}, evidently this distillate is composed of a single body, although analysis alone is not sufficient to determine whether its composition is represented by the formula $C_{11}H_{22}$ or $C_{12}H_{24}$.

Above 192°, no distillates collected in appreciable amounts below 210°. At 212°–214° a larger quantity collected, evidently corresponding to a hydrocarbon boiling at 216°, which has been found in other oils. A determination of its specific gravity gave 0.8483. It absorbed bromine equivalent to 4.29 per cent. and contained 0.04 per cent of sulphur. A determination of carbon and hydrogen gave the following percentages: —

0.1555 gram of the oil gave 0.4887 gram CO_2, and 0.1992 gram H_2O.

	Calculated for $C_{12}H_{24}$.	Found.
C	85.71	85.72
H	14.29	14.23

A small quantity of nitro product was formed, when this distillate was treated with nitric and sulphuric acids, and fuming sulphuric acid then

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removed more of the nitro compound from the oil. The oil shaken with sodic hydrate imparted a yellow color to the alkaline solution; it was then redistilled for analysis: —

0.1590 gram of the oil gave 0.4984 gram CO_2, and 0.2037 gram H_2O.

	Calculated for $C_{11}H_{22}$.	Found.
C	85.71	85.48
H	14.29	14.23

A determination of the specific gravity of the oil after treatment with acids gave 0.8484, the same value as was obtained for the crude distillate. It is therefore evident that this petroleum consists mainly of a single series of hydrocarbons, with a mere trace of aromatic hydrocarbons C_nH_{2n-6}. What this series is does not appear from these results, at least so far as its relation to the series of hydrocarbons hitherto discovered in petroleum. In the proportions of carbon and hydrogen, the series C_nH_{2n} is indicated. Neither the crude oil nor any of these distillates deposit paraffine, even at low temperatures. The higher distillates are thick and viscous, light yellow in color, and unquestionably are undecomposed constituents of the crude oil.

With nitric and sulphuric acids the constituents described in this paper are as slightly affected as are the naphtenes in the Russian oil. This fact, together with the results of analysis corresponding to the series C_nH_{2n-6}, and the high specific gravity, point to a similar composition for these bodies, and the small proportion of the crude oil distilling below 220° seems, therefore, to be composed almost exclusively of naphtenes, which is the first instance of an American petroleum having been found containing these hydrocarbons in any considerable quantity. The higher distillates from this petroleum will receive further attention in connection with the corresponding portions of other American oils.

Having at hand a specimen of petroleum from Oregon, resembling the heavier California products, with a specific gravity nearly the same as that of the South American oil described above, it seemed of sufficient interest to submit it to an examination in connection with that of the South American oil. The crude oil was very thick and dark, with a specific gravity, 0.9597 at 20°. Like the California oils, as shown by Peckham, it contains a large percentage of nitrogen compounds. A Kjeldahl determination gave 0.868 per cent of nitrogen. This is also a high sulphur oil, as shown by a combustion which gave 1.19 per cent of sulphur. It is also a high carbon oil; a combustion gave 86.06 per cent of carbon, and 11.87 per cent of hydrogen. A very small proportion

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distils under atmospheric pressure without decomposition; even under diminished pressure, the amounts distilling below 250° are small.

In attempting to separate the constituents of this oil from the distillates first collected *in vacuo*, the portions below 250°, about the same in amount as the corresponding distillates from the South American oil, were carried through ten distillations under atmospheric pressure, which brought together larger quantities at 169°–170°, 190°–191°, and 212°–214°. The portions collected at 85°–150° in the first distillation gave as its specific gravity at 20°, 0.8755; the distillate 150°–225°, 0.9038; and the distillate 225°–250°, 0.9271. After the tenth distillation, the fraction 170°–171° gave as its specific gravity, 0.8200; the fraction 189°–190°, 0.8330; and the fraction 212°–214°, 0.853. A combustion of the fraction 189°–190° gave the following percentages of carbon and hydrogen: —

0.1510 gram of the oil gave 0.4757 gram CO_2, and 0.1835 gram H_2O.

C	85.90
H	13.51

After purification with nitric and sulphuric acids, the composition of this oil was not essentially changed: —

0.1484 gram of the oil gave 0.4643 gram CO_2, and 0.1839 gram H_2O.

	Calculated for C_nH_{2n}.	Found.
C	85.71	85.33
H	14.29	13.77

The fraction 212°–214°, without purification, gave the following results: —

0.1457 gram of the oil gave 0.4625 gram CO_2, and 0.1757 gram H_2O.

C	86.46
H	13.40

By treatment with a mixture of nitric and sulphuric acids, and then with fuming sulphuric acid, this distillate was only slightly affected: —

0.1343 gram of the oil gave 0.4231 gram CO_2, and 0.1677 gram H_2O.

	Calculated for C_nH_{2n}.	Found.
C	85.71	85.90
H	14.29	13.88

Unfortunately the quantities of these distillates were too limited to permit of further examination. The principal object, however, — to ascer-

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tain whether any members of the series C_nH_{2n+2} were present at all, or the aromatic hydrocarbons C_nH_{2n-6} in more than minute proportions, — was attained. Evidently the main body of this oil is composed of a series with less hydrogen than the former and more than the latter. The oil distills in such small quantities, even *in vacuo,* below 220°, it will be interesting to ascertain the composition of the distillates above this point.

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THE GENERA OF NORTH AMERICAN MELANOPLI.

By Samuel H. Scudder.

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THE GENERA OF NORTH AMERICAN MELANOPLI.

By Samuel H. Scudder.

Presented January 13, 1897.

In an extended paper upon the Melanopli (Pezotettiges Brunn.) to be published by the U. S. National Museum, I have treated this group monographically, with full descriptions of each genus and species, accompanied by keys for their determination. As some time must elapse before the final publication of this work, which was completed in December, 1895, and will be abundantly illustrated, I present herewith, by permission of the Museum, the table therein given for the determination of the genera of Melanopli, appending a few remarks to show how the species already known are distributed among them. The fuller paper will contain the complete revision, with full synonymy.

Table of the Genera of North American Melanopli.

A^1. Lateral margins of subgenital plate (last ventral segment) of male, as seen laterally, straight throughout or very slightly convex, never at all abruptly ampliate at the base.

b^1. Body exceptionally slender; mesosternal lobes subattingent in both sexes; prozona three times as long as metazona . . . *Gymnoscirtetes.*

b^2. Body not exceptionally slender; mesosternal lobes in both sexes so widely separated that the interspace between them is at most twice as long as broad; prozona not more than twice as long as metazona.

c^1. Interspace between mesosternal lobes of female decidedly transverse, sometimes twice as broad as long; of male sometimes transverse, sometimes quadrate or subquadrate; tegmina lobiform, linear, or wanting.

d^1. Interspace between mesosternal lobes of male decidedly transverse, as broad as or broader than the lobes; pronotum without lateral carinæ; tegmina ovate or wanting . . . . *Netrosoma.*

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d^2. Interspace between mesosternal lobes of male quadrate or subquadrate, or, if feebly transverse (as in Paradichroplus), not so broad as the lobes, and then the pronotum furnished with lateral carinæ; tegmina ovate or linear.

e^1. Subgenital plate of male pyramidal, pointed, a slight tubercle extending beyond its posterior margin, but the margin extending well beyond the apex of the supraanal plate.

Paradichroplus.

e^2. Subgenital plate of male more or less conically protuberant apically, but its interior apical margin not surpassing or barely surpassing the apex of the supraanal plate.

f^1. Apical tubercle of subgenital plate small, extending but a short distance beyond the supraanal plate; cerci of male abruptly narrowed before the middle by excision of the inferior margin, the apical half narrow; lateral carinæ of pronotum wholly wanting . . . . . *Phædrotettix.*

f^2. Nearly the whole subgenital plate forming a blunt conical tubercle projecting some distance beyond the supraanal plate; cerci of male forming broad, apically decurved, subfalcate laminæ; lateral carinæ of pronotum more or less distinct . . . . . *Conalcæa.*

c^2. Interspace between mesosternal lobes of female generally longer than broad, sometimes quadrate, rarely feebly transverse;* of male never at all transverse (except feebly in Sinaloa and Cephalotettix); tegmina variable.

d^1. Tegmina never fully developed, rarely as long as the pronotum, lateral and ovate or linear, or wholly wanting; hind margin of pronotum distinctly truncate; fore and middle femora of male (except in Phaulotettix) distinctly more gibbous than in the female.

e^1. Furcula of male wanting, or forming a pair of brief lobes, at most no longer than broad.

f^1. Last dorsal segment of male furnished mesially with a pair of slightly protuberant rounded lobes; cerci of male compressed laminate, beyond the slightly narrowing basal portion equal or subequal, the tip curved downward or inferiorly angulate at apex.

* Cephalotettix, in which the female is unknown, is placed in this division.

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g^1. Prosternal spine erect; interspace between mesosternal lobes of male nearly twice as long as broad; fore and middle femora of male noticeably gibbous; subgenital plate of male terminating in a large conical tubercle. *Barytettix.*

g^2. Prosternal spine retrorse; interspace between mesosternal lobes of male only a little longer than broad; fore and middle femora of male only slightly gibbous; subgenital plate of male with no apical tubercle. . *Phaulotettix.*

f^2. Last dorsal segment of male entirely without projecting lobes or furcula in any form, unless as exceptionally broad and short sessile plates; cerci of male (except in Cephalotettix) apically acuminate or curved upwards.

g^1. Head large, and eyes, at least in male, large and very prominent, the breadth of the head distinctly exceeding the greatest width of the pronotum; interspace between mesosternal lobes of male slightly transverse. *Cephalotettix.*

g^2. Head normal and eyes not very prominent even in the male, so that the breadth of the head does not exceed the greatest width of the pronotum; interspace between mesosternal lobes of male distinctly longer than broad.

h^1. Tegmina lobiform; subgenital plate of male protruding beyond the tip of the supraanal plate by less than half the length of the latter; cerci of male compressed, subequal, the tip broad . . . *Rhabdotettix.*

h^2. Tegmina linear; subgenital plate of male protruding beyond the tip of the supraanal plate by much more than half the length of the latter; cerci of male tapering from the base, the tip acuminate . . *Cyclocercus.*

e^2. Furcula of male consisting of a pair of parallel, attingent, cylindrical processes, generally at least twice as long as broad.

f^1. Tegmina lobiform; interspace between mesosternal lobes of male slightly transverse; cerci of male forming compressed subequal laminæ . . . . . *Sinaloa.*

f^2. Tegmina wanting; interspace between mesosternal lobes of male longer than broad; cerci of male styliform, conical. *Paraidemona.*

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d^2. Tegmina fully developed or abbreviate, never much if any shorter than the pronotum; hind margin of pronotum distinctly angulate; fore and middle femora scarcely more gibbous in the male than in the female (except in some species of Campylacantha).

e^1. Tegmina fully developed; disk of pronotum nearly flat, the lateral lobes nearly at right angles to it, the posterior margin rectangulate or subrectangulate; prosternal spine quadrate, appressed, broadly truncate . . . . . *Aidemona.*

e^2. Tegmina abbreviate; disk of pronotum tectiform, the posterior margin obtusangulate; prosternal spine more or less conical and acuminate.

f^1. Head not prominent, the summit very slightly arched longitudinally; prosternal spine erect; furcula of male composed of projecting cylindrical fingers; surface of body very feebly pilose . . . . . *Hypochlora.*

f^2. Head prominent, the summit strongly arched longitudinally; prosternal spine more or less retrorse; furcula of male reduced to slight scarcely projecting lobes; surface of the body rather densely pilose . . . . *Campylacantha.*

A^2. Lateral margins of subgenital plate of male suddenly ampliate to a considerable degree at the base; or if not to a considerable degree, then the entire margin rather strongly convex or sinuate.

b^1. Subgenital plate of male furnished with a distinct subapical tubercle (*i. e.*, one in which the apical margin does not pass through and form a part of the summit of the tubercle, but where it is distinctly separated from the summit), but not otherwise tumescent (see note under A^2 b^2).

c^1. Median carina of pronotum well developed and equally developed throughout, accompanied on the front of the prozona by distinct lateral carinæ; prosternal spine sharply acuminate; tubercle of subgenital plate directed wholly backward, occupying the middle of the terminal portion of the plate; furcula distinctly developed. *Eotettix.*

c^2. Median carina of pronotum feebly developed and generally much more feebly on the prozona than on the metazona, accompanied by no lateral carinæ whatever; prosternal spine bluntly acuminate; tubercle of subgenital plate directed upward, or upward and backward, occupying the upper extremity of the terminal portion of the plate.

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d^1. Body relatively slender and compressed, not much enlarged at the metathorax, particularly in the male; disk of the pronotum tectiform,* the prozona not distinguished from the metazona either by its plane or by any lack of a median carina, which latter is generally marked in color; pronotum fully half as long again as broad; hind femora long and slender; apical tubercle of male abdomen prominent; furcula present as distinctly projecting lobes; terminal segments of female abdomen not abbreviated, the ovipositor fully exserted . . . . . *Hesperotettix.*

d^2. Body relatively short and stout, considerably enlarged at the metathorax even in the male; disk of pronotum generally convex transversely; the prozona slightly and independently tumid with no median carina, thus distinguishing it from the metazona;† hind femora relatively short and stout; apical tubercle of male abdomen not very prominent; furcula scarcely or not apparent; terminal segments of female abdomen abbreviated, the ovipositor only partially exserted . . . . . *Æoloplus.*

b^2. Subgenital plate of male with no distinct subapical tubercle, but often apically prolonged or tumescent.‡

c^1. Meso- and metastethium together, in both sexes, no longer or scarcely longer than broad; metastethium narrowing but little posteriorly, so that the portion behind the metasternal lobes is but little narrower than the rest, rarely (in the male) less than three fourths its width; cerci of male very simple, subconical, straight; ovipositor half concealed . . . . . *Bradynotes.*

c^2. Meso- and metastethium together, at least in the male and nearly always in both sexes, distinctly longer than the width of the metastethium; the latter rapidly narrowing posteriorly, so that the portion behind the metasternal lobes is not, or is hardly more than, one half the greatest width of the metastethium; cerci of male variable; ovipositor generally fully exserted.

d^1. Interspace between mesosternal lobes of male distinctly transverse, § as broad or nearly as broad as the lobes themselves; of

* This feature is not so apparent in some species as in others.

† This feature is less marked in some species than in others.

‡ There is a minute subapical tubercle in some species of the flabellifer group of Melanoplus, but in these the male cerci are exceptionally broad; while in the species of the alternate category (A^2 b^1) they are very slender and tapering.

§ In many cases the interspace is truncato-cuneiform or broadly clepsydral, in which cases the breadth is to be measured in the middle.

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the female distinctly or strongly transverse, fully as broad as or (and generally) broader than the lobes; metasternal lobes of male generally distinctly distant, occasionally approximate; of the female generally more distant, the interspace in the latter generally as wide as or wider than the frontal costa; tegmina typically abbreviate.

e^1. Face almost vertical; eyes small but prominent and widely distant; pronotum constricted in the middle, with deeply impressed transverse sulci, and the lateral lobes not obliquely truncate apically in front; distinct lateral carinæ.

Dendrotettix.

e^2. Face a little oblique; eyes rather large, not very prominent and not very distant; pronotum not, or but feebly, constricted in the middle, with generally feebly impressed transverse sulci, and the lateral lobes obliquely truncate apically on the anterior section . . . . . *Podisma.*

[f^1. Pronotum of subequal width, the sides nearly parallel; subgenital plate of male normal . . . . . Podisma *s. s.*

f^2. Pronotum enlarging posteriorly, conspicuously in the female; subgenital plate of male exceptionally expanded, laterally tumid, and elevated premarginally . Eupodisma.]

d^2. Interspace between mesosternal lobes generally longer or much longer than broad in the male, almost never (cf. *Mel. montanus* Thom.) in the least broader than long even when the sides of the interspace are posteriorly divergent; generally quadrate in the female, but more variable than in the other sex, sometimes as narrow as there, more often subtransverse, occasionally in some brachypterous forms (as in *Mel. artemisiæ* Brun., *Mel. militaris* Scudd., *Mel. altitudinum* Scudd., and Asemoplus) distinctly transverse; in both sexes always distinctly, generally much, narrower than the lobes (except in the females of the cases just cited, where they are barely narrower); metasternal lobes of male generally attingent or subattingent, rarely only approximate; of the female less distant than in the alternate category ($A^2\ b^2\ c^1\ d^1$), generally approximate or subapproximate, the interspace generally narrower than the frontal costa; typically the tegmina are completely developed.

e^1. Face almost vertical or a little oblique, its angle with the fastigium rarely less than 75°; eyes rounded oval, never more generally less than half as long again as broad; portion of

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metasternum lying behind the lobes transverse, more than twice as broad as long; tegmina normally present.

f^1. Tegmina always present; sides of first abdominal segment with a distinct tympanum.

g^1. Fastigium of vertex plane or convex; eyes separated widely, the space between them twice as broad as the frontal costa; pronotum furnished with distinct percurrent lateral carinæ; tegmina abbreviate; cerci apically acuminate . . . . . *Paratylotropidia.*

g^2. Fastigium of vertex more or less depressed or with elevated lateral margins; eyes separated narrowly, at most but little further apart than the width of the frontal costa; pronotum with indistinct* or no lateral carinæ; tegmina fully developed or abbreviate; cerci variable, rarely acuminate apically.

h^1. Inferior genicular lobe of hind femora with at least a darker basal spot or transverse band; cerci of male variable, often enlarging apically.

i^1. Dorsum of pronotum rarely or never twice as long as the average breadth, generally only half as long again, even in the male, generally constricted more or less in the middle; antennæ even when longest (as in *Mel. packardii* Scudd., *Mel. nitidus* Scudd.) no longer than the hind femora, and only twice as long as the pronotum alone; face rarely as declivent as in Paroxya; prozona usually a half longer than the metazona.

j^1. Head not large in proportion to pronotum, nor prominent, but little longer than the prozona, unless (as in *Mel. spretus* Uhl. *e. g.*) the latter is distinctly transverse; pronotum in no way subsellate, nor flaring in front; tegmina, when fully developed, narrow, rarely (*Mel. fasciatus* Barnst.,† *Mel. dawsoni* Scudd.,) rather broad, but then very distinctly tapering, more or less tapering in distal half, at

* In a few species they are tolerably distinct.

† In form of tegmina and sparseness of neuration, the macropterous form of this species is the Melanoplus most nearly allied to Phœtaliotes, and like it, the species is dimorphic as to tegmina.

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a distance from the apex equal to the breadth of the tegmina distinctly narrower than the metazona, the intercalaries and cross-veins of the discoidal area relatively numerous, at least in the apical fourth and usually throughout, the venation in general sharp and clearly defined, the *area intercalata* distinctly defined by the adjustment of the veins at its distal extremity, the humeral vein straight and apically arcuate, nearly always terminating either on the apical margin or but a short distance before it, running for some distance almost exactly parallel to the costal margin or merging insensibly into it; cerci of male very variable, very rarely (*Mel. flabellatus* Scudd., *Mel. puer* Scudd.) styliform, and then the subgenital plate is either exceptionally broad or only moderately narrow, and the apical margin elevated.

Melanoplus.

j^2. Head large in proportion to pronotum, nearly half as long again as the long prozona; pronotum faintly subsellate, feebly flaring in front to receive the head; tegmina, when fully developed, broad and subequal, hardly tapering in the distal half, at a distance from the apex equal to the breadth of the tegmina as broad as the metazona, the intercalaries and cross-veins of the discoidal area everywhere few, the venation in general loose and ill defined, the *area intercalata* not distinctly marked by the adjustment of the veins at its distal extremity, the humeral vein broadly sinuous, terminating on the costal margin at least as far before the apex as the breadth of the tegmina, nowhere running closely parallel to that margin nor merging into it; cerci of male styliform, the subgenital plate very narrow, the margin not apically elevated . . . . . *Phœtaliotes.*

i^2. Dorsum of pronotum twice as long as average breadth, at least in the male, with no median constriction; antennæ, at least in the male, generally longer than the hind femora and much more than

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twice as long as the pronotum, generally twice as long as head and pronotum together; face more declivent than in Melanoplus; prozona only about a third longer than the metazona . . . *Paroxya.*

h^2. Inferior genicular lobe of hind femora wholly pallid, with no dark basal spot or transverse band; cerci of male conical or subconical or basally bullate, always apically pointed.

i^1. Subgenital plate of male terminating in a pronounced tubercle; prosternal spine slender. *Pœcilotettix.*

i^2. Subgenital plate of male, even when apically angulate, not furnished with an apical tubercle; prosternal spine stout.

j^1. Relatively heavy bodied; dorsal disk of the prozona tumid independently of the metazona; pronotum distinctly angulate or convex behind; the portion of the metasternum lying behind the lobes laterally extended, reaching to the coxæ; tegmina fully developed or abbreviate but overlapping, with many longitudinal veins; cerci of male very stout and bullate on basal half or more; abdomen of female bluntly rounded apically, the posterior segments much abbreviated; ovipositor but slightly exserted . . . . . *Œdaleonotus.*

j^2. Relatively slender bodied; dorsal disk of prozona not tumid independently of the metazona; pronotum truncate posteriorly; portion of metasternum lying behind the lobes laterally abbreviated, much narrower than the width between coxæ; tegmina linear, lateral, distant, with only a few longitudinal veins; abdomen of female tapering regularly to a pointed tip; ovipositor normally exserted . . . . . *Asemoplus.*

f^2. Tegmina wanting; sides of first abdominal segment with no tympanum . . . . . *Philocleon.*

e^2. Face rather strongly oblique, the angle it makes with the fastigium varying about from 55° to 67°; eyes elongate, almost or quite twice as long as broad; portion of metasternum lying

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behind the lobes subtriangular, not greatly broader than long; tegmina linear and lateral or absent . . . . *Aptenopedes.*

Gymnoscirtetes Bruner MS. contains a single undescribed species from Florida, of a somewhat anomalous character.

Netrosoma gen. nov. is based on two species from Mexico, both of them new.

Paradichroplus Brunner is represented in North America by two species from Mexico and Central America, *mexicanus* Brunn., and *varicolor* Stål.

Phædrotettix gen. nov. has but a single and undescribed species, which comes from Mexico and southern Texas.

Conalcæa gen. nov. has three species, all of them new; they occur in Mexico and southwestern New Mexico.

Barytettix gen. nov. is known only from Lower California, where it is represented by two undescribed species.

Phaulotettix gen. nov. contains a single and undescribed species from Mexico.

Cephalotettix gen. nov. is also monotypic and the species is new and from Mexico.

Rhabdotettix gen. nov. contains three species from Texas and Mexico, *pilosus* Stål and two undescribed forms.

Cyclocercus gen. nov. also contains three species found in northern Mexico and southern Texas, all of them new.

Sinaloa gen. nov. is founded upon a single, as yet unpublished Mexican species.

Paraidemona Brunner is found in Texas and northern Mexico, and is restricted to *punctata* Stål and a new species, the other species referred to it by Brunner being placed elsewhere.

Aidemona Brunner is confined to *azteca* Sauss., found in Mexico.

Hypochlora Brunner was originally founded on three species, but is here restricted to only one of them, *alba* Dodge, found on the eastern margin of the Rocky Mts.

Campylacantha gen. nov. is composed of four species found in the western United States east of the Rocky Mts., from Nebraska to Texas, and in Durango, Mexico. The species are *acutipennis* Scudd., *olivacea* Scudd., *vivax* Scudd., and one undescribed species.

Eotettix gen. nov. is founded on a single undescribed species from Florida.

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Hesperotettix Scudder is found across the continent, but only a single species, *brevipennis* Thom., is known east of the Great Plains, and that has been found only on or near the Atlantic border. The other species are *viridis* Thom., *pacificus* Brun. (undescr.), *speciosus* Scudd., and four new species, including two which have often been confounded with one of the foregoing.

Æoloplus gen. nov. is confined to the western half of the United States from the Yellowstone to the Mexican border. I have seen no species from further east than western Kansas and Nebraska, so that it does not appear to reach the prairie region. There are ten species, of which those already published are *regalis* Dodge, *chenopodii* Brun., *turnbulli* Thom., and *plagosus* Scudd.

Bradynotes Scudder is confined to the extreme northwestern United States, and contains seven species, of which the only ones already described are *hispida* Brun., and *obesa* Thom. (*opimus* Scudd.).

Dendrotettix Riley has but a single and dimorphic species, *quercus* Ril. (*longipennis* Ril.), ranging from Missouri to Texas.

Podisma Latreille is used in replacement of Pezotettix Burmeister for reasons given in *Psyche* (vii, 195). It has a wider distribution than any other genus of Melanopli, being found in Europe and temperate Asia, as well as in America. The American species occur in two great districts, one in the west from Alberta to northern New Mexico, the other in the east from western Ontario and New York to Maine. There are eight American species, of which those already described are the following: *glacialis* Scudd., *stupefacta* Scudd., *dodgei* Thom., *marshallii* Thom., and *oregonensis* Thom. Eupodisma is a subgeneric term for *primnoa* Fisch. de W. of Siberia.

Paratylotropidia Brunner is based on an undescribed species found from Dakota to Texas.

Melanoplus Stål is the dominant genus, with one hundred and thirty-one species, but it is confined to North America. These species have been grouped into twenty-eight series, but as, on account of its pre-eminent importance, this genus is treated separately in another paper in press, no further account of the species is given here.

Phœtaliotes gen. nov. is based upon a single species, *nebrascensis* Thom., found in the western part of the Mississippi basin, and beyond its latitudinal limits from Alberta to Mexico.

Paroxya Scudder has three species, mostly confined to the Atlantic and Gulf States; they are *atlantica* Scudd., *hoosieri* Blatchl., and *floridana* Thom.

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Pœcilotettix gen. nov. is represented by three species: *picticornis* Thom., and two new species, found only on the Pacific coast near our southern borders.

Œdaleonotus gen. nov. is based on the polymorphic species, *collaris* Scudd., found on the Pacific coast.

Asemoplus gen. nov. is based on a single species, *montanus* Brun., found in the extreme northwestern United States.

Philocleon gen. nov. has but a single species, *nigrovittatus* Stål, from Mexico.

Aptenopedes Scudder is known only from the Gulf States, with the three species, *sphenarioides* Scudd., *rufovittata* Scudd., and *aptera* Scudd.

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CYCLE IN THE LIFE OF THE INDIVIDUAL (ONTOGENY) AND IN THE EVOLUTION OF ITS OWN GROUP (PHYLOGENY).

By Alpheus Hyatt.

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CYCLE IN THE LIFE OF THE INDIVIDUAL (ONTOGENY) AND IN THE EVOLUTION OF ITS OWN GROUP (PHYLOGENY).*

By Alpheus Hyatt.

Presented October 14, 1896.

The organic cycle, as generally understood both by laymen and scientists, and as usually described in literature, is, as a rule, considered from a physiological rather than a structural point of view. The development of the young, and the attainment of the adult or comparatively permanent stage, complete the progressive stages. Old age, accompanied by losses of characteristics and functions and consequent weakening of the body, is retrogressive, and brings on second childhood, thus completing the cycle in the ontogeny.

My purpose to-night is to show that the cycle is also represented in the life history of the individual by definite structural changes, and that these have direct correlations with the history of the changes in the forms of the group while evolving in time.†

The fundamental discoveries that are more than any other directly useful in the study of the phenomena of the cycle, both in ontogeny and phylogeny, may be briefly noticed as follows.

The opinion that the higher animals are complex colonial aggregates of cells, which in structure are equivalents to the lowest and minutest adult forms of the animal kingdom, the unicellular bodies of Protozoa.

* This paper was in part read before the Academy as a general summary of the phenomena of cycles, but does not assume to be an exhaustive or even complete account of the literature or theoretical views treated of.

† These correlations have been more fully stated in a number of publications by the author, especially "Genesis of the Arietidæ," Smithsonian Contribution 673, and Mem. Mus. Comp. Zoölogy, Vol. XVI.; "Bioplastology and the Related Branches of Scientific Research," Proc. Bost. Soc. Nat. Hist., Vol. XXVI.; and "Phylogeny of an Acquired Characteristic," Proc. Am. Phil. Soc., Vol. XXXII. No. 143.

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has been steadily gaining in probability since it was first announced by Oken in 1805, in "Die Zeugung," Frankfurt bei Wesche, 8vo.* This work we have not yet seen, but in the first edition of the "Naturphilosophie," Jena, 1809, II., XII. Buch, Zoogenie, he describes protoplasm as 'Punctsubstanz' and as giving rise to the 'Blasenform oder Zellform' in both animals and plants. Oken considered the lower animals "Polypen, Medusen, Beroen, kurz alle Gallertthiere," to be composed of 'Punctsubstanz.' The nerves, the cartilage, and bones of higher animals were considered as modifications of this form of 'protoplasm,' but the skin and fleshy parts, including the viscera, were described as cellular, "dem Fleisch liegt die Bläschenform zur Grunde"; again, on p. 30, "die Eingeweide, welche am meistens aus Zellengeweb bestehen." Oken, in XII., VIII. Buch, treats of the subject we are more immediately interested with, and writes as follows: "Pflanzen und Thiere können nur Metamorphosen von Infusorien sein, . . . im kleinsten sind sie nur infusoriale Bläschen die durch verschiedene Combinationen sich verschiedene Gestalten und zu höheren Organismen aufwachsen," and also adds, on p. 29, in anticipation of one of the points advanced by the author in his "Larval Theory of the Origin of Cellular Tissues," † "auch besteht der Samen aller Thiere aus Infusorien."

This author directly compares his cystic or intestinal animals, Infusoria, with ova, and speaks of them as oözoa, and in the preface to the English edition of his Physiophilosophy, London, 1847, Ray Society, he writes that all organic beings originate from and consist of vesicles or cells. "Their production is nothing else than a regular agglomeration of Infusoria; *not, of course, of species previously elaborated or perfect, but of mucous vesicles or points in general which first form themselves by their union or combination* into particular species." Oken's view was based on the resemblances existing between the Protozoa and the cells in the tissues

* Through the kindness of Prof. George Baur I have received his copy of this book, and find to my surprise that it contains quite different statements of Oken's theory from that of the "Naturphilosophie." This author made great advances in knowledge between 1805 and 1809. In "Die Zeugung" he relies for the proof that the more complex animals are descended from what we now call unicellular organisms upon the constant presence of some of these in decaying flesh, assuming that they are the disintegrated elements of the body itself and not independent productions.

He makes also, on p. 128, distinct statements asserting the parallelism of the development of the individual to the evolution of the organic kingdom, but gives only fanciful analyses in support of this position.

† Proc. of the Bost. Soc. Nat. Hist., Vol. XXIII., March 5, 1884.

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of the Metazoa; and it is evident he is entitled to be considered the first teacher of the unicellular doctrine, an honor now universally given to Von Siebold.

However imperfect and imaginative the results as compared with the more objective statements of later observers, the author who wrote such sentences as these had as clear ideas as the knowledge of his time permitted, and was the Haeckel of the early part of this century, and, like him, a great and successful leader, making many errors but also many discoveries and "blazing out" some of the paths that we are still following.

Meckel* seems to have been the first author who brought together and stated in a clear way the scattered observations and ideas with regard to the correlations existing between the transient stages of development of the individual and the so-called permanent modifications represented by the similar characters in the adult stages of similar forms.

Meckel says: "Es giebt keinen guten Physiologen, den nicht die Bemerkung frappirt hätte, dass die ursprüngliche Form aller Organismen eine und dieselbe ist, und dass aus dieser einen Form sich alle, die niedrigsten, wie die höchsten, so entwickeln, dass diese die permanenten Formen der ersten nur als vorübergehende Perioden durchlaufen. Aristotles, Haller, Harvey, Kielmeyer, Autenrieth, und mehrere andere haben diese Bemerkung, entweder im Vorübergehen gemacht, oder, besonders die letzten, hervorgehoben und für die Physiologie ewig denkwürdige Resultäte daraus abgeleitet.†

"Von diesen niedrigsten Wirbelthieren an bis zu den höchsten Geschlechtern lässt sich die Vergleichung zwischen dem Embryo der höhern Thiere und den niedern im vollkommenen Zustande vollständiger und treffender durchführen.

"In der That giebt es ja eine Periode wo der Embryo des höchsten Thieres, wie schon Aristotles sagt, nur die Gestalt einer Made hat, wo er ohne äussere und innere Organisation, bloss ein kaum geformtes Klümpchen von Polypensubstanz ist. Ungeachtet des Hervortretens von Organen bleibt es doch nach, wegen des gänzlichen Mangels eines innern Knochengerüstes, eine zeitlang Wurm und Mollusk, und tritt

* Meckel, "Entw. e. Darstellung d. zw. d. Embryonalzustände d. höhern Thiere u. d. perman. d. niedern stattfindenden Parallele." Beitr. z. vergleich. Anat., II., Leipzig, 1811, pp. 1–148. Meckel speaks of his publications as only preparatory to more extended researches.

† I desire to express my indebtedness to Miss M. F. Slack, Librarian of Mus. Comp. Zoölogy, for her assistance in finding this important reference.

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erst später in die Reihe der Wirbelthiere, wenn gleich Spuren der Wirbelsäule schon in den frühesten Perioden seinen Anspruch auf diese Stelle in der Reihe der Thiere beglaubigten."

It is very obvious, from these statements of Meckel, that the correlation of embryology and the epembryonic stages of the individual with the permanent modifications of animals of simpler construction was understood, as far as was possible with existing knowledge, from the time of Aristotle, and that it was to a greater or less extent a working hypothesis at that time, and, as declared by him, had been helpful in giving a clearer understanding of the development of the individual and of the relations of the individual to the whole animal kingdom.

The next step was taken by Von Baer, in dividing the animal kingdom into four types and in limiting this general statement to animals occurring within each of these types. He also considered it highly probable (not barely possible, as it is quoted by some writers) that the earliest stages of the embryo resemble in aspect the adult stages of the lowest grade of forms in the animal kingdom. He had in mind in this statement the modern view of the affinities of the earliest stages of the embryo or its repetitions of the characteristics of Protozoa,* so far as the knowledge of his time permitted.

Von Baer endeavored to prove that each of the four types had similar embryos, and that the type characters were determinable at early stages in the ontogeny. Both Von Baer and Louis Agassiz were pupils of Ignatius Döllinger, an embryologist who published nothing. Both of these eminent men have recognized him as their master in embryology, but have given no definite statement of what they were taught by him. Louis Agassiz accepted Von Baer's opinions, and subsequently enlarged them, when he published his work on fossil fishes, by the introduction of the element of succession in time, and thus laid the basis for all more recent investigations.

Agassiz gave the fullest expression of his views in "Twelve Lectures on Comparative Embryology," Lowell Institute, Boston, 1848–49, subsequently published in pamphlet form. One wonders, as he reads, how any man holding such views could have held his mind closed to the conclusion that animals were evolved from simpler or more primitive forms. The effect of theoretical preconceptions in closing the mind to the reception of new ideas never had a stronger illustration. Louis Agassiz, in 1849, had all the facts essential for building up an hypothesis of evolution that

* Entwickelung. d. Thiere, Scholion V. pp. 119, 120, etc.

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would have placed him in the history of science on the same line with Lamarck and Darwin.

He states in fourth lecture, p. 26, as follows: "The results thus far obtained in the lectures which I have delivered can be expressed as follows. There is a gradation of type in the class of Echinoderms, and indeed in every class of the animal kingdom, which, in its general outlines, can be satisfactorily ascertained by anatomical investigation; but it is possible to arrive at a more precise illustration of this gradation by embryological data. The gradation of structure in the animal kingdom does not only agree with the general outlines of the embryonic changes. The most special comparison of these metamorphoses with full-grown animals of the same type leads to the fullest agreement between both, and hence to the establishment of a more definite progressive series than can be obtained by the investigation of the internal structure. These phases of the individual development are the new foundations upon which I intend to rebuild the system of zoölogy. These metamorphoses correspond, indeed, in a double sense, to the natural series established in the animal kingdom: first, by the correspondence of the external forms, and secondly, by the successive changes of structure, so that we are here guided by the double evidence upon which the progress in zoölogy has, up to this time, generally been based.

"Their natural series again correspond with the order of succession of animals in former geological ages, so that it is equally as true to say that the oldest animals of any class correspond to their lower types in the present day as to institute a comparison with the embryonic changes, and to say that the most ancient animals correspond with the earlier stages of growth of the types which live in the present period. In whatever point of view we consider the animal kingdom, we find its natural series agree with each other; its embryonic phases of growth correspond to its order of succession in time, and its structural gradation, both to the embryonic development and the geological succession, corresponds to its structure; and if the investigations had been sufficiently matured upon this point, I might add that all these series agree also in a general way with the geographical distribution of animals upon the surface of our globe, but this is a point upon which I am not yet prepared to give full and satisfactory evidence. So much for the views referring to embryology in its bearing upon zoölogical classification."

And again on page 27: —

"However, another step had to be made to show a real agreement between the earlier types of animals and the gradual development of the

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animal kingdom, which has been the last progress in our science of fossils, namely, to show that these earlier types are embryonic in their character; that is to say, that they are not only lower in their structure when compared with the animals now living upon the surface of our globe, but that they actually correspond to the changes which embryos of the same classes undergo during their growth. This was first discovered among fishes, which I have shown to present, in their earlier types, characters which agree in many respects with the changes which young fishes undergo within the egg. Without entering into all the details of these researches, I will conclude by saying it can now be generally maintained that earlier animals correspond not only to lower types of their respective classes, but that their chief peculiarities have reference to the modifications which are successively introduced during the embryonic life of their corresponding representatives in the present creation. To carry out these results in detail must now be, for years to come, the task of paleontological investigations." *

* Prof. George Baur of Chicago University has, since the above was written, called my attention to Carl Vogt's "Embryologie des Salmones," published under the general title of "Poissons d'Eau Douce," par L. Agassiz, Neuchatel, 1842. I take the following quotations from his pages.

Vogt says, on the second page of the Preface, after stating that Louis Agassiz had handed this part of the work over to him: "En me confiant une tâche aussi honorable, mon célèbre ami n'est cependant point resté étranger à mes recherches. Nous avons discuté ensemble les faits capitaux, à mesure que l'observation me les *révélait; souvent même nous les avons examinés de nouveau en commun*, et lorsque j'eus rédigé mon travail, c'est encore lui qui a bien voulu le revoir."

Again, on pages 256. 257: —

"*Depuis longtemps on a discuté dans des sens très-divers la question de l'analogie entre les phases du développement des animaux vivants maintenant et les changements qui sont survenus dans l'ordre de succession des espèces fossiles*; mais faute de renseignemens précis sur l'on ou l'autre des côtés de la question, ces généralisations sont restées dans un vague très-facheux pour les vrais progrès de la science. Sans entrer ici dans des considérations hasardées, sans aborder le domaine encore trop peu cultivé de la plus grande analogie qu'offrent entre elles les différentes parties du corps des poissons fossiles les plus anciens et que l'on pourrait paralléliser avec l'homogénéite des tissus primitifs de l'embryon, je me bornerai à faire ressortir quelques points qui ne sauraient plus être contestés et qui, je l'espère, feront faire de nouvelles recherches sur l'ensemble de la question."

Vogt concludes, on page 260, as follows: —

"On pourra donc dire à l'avenir, en restant rigoureusement dans les limites de l'observation, qu'à certains égards, les espèces fossiles d'une classe parcourent dans leur succession historique des métamorphoses semblables à celle que subissent les embryons en se développant; ou vice-versa, que les embryons des animaux de notre époque passent, dans les différentes époques de leur développement par des

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Perhaps in consequence of pressure of other work or of his theoretical views, Louis Agassiz seemed to have lost sight of the great importance of continuing his researches upon the meaning and correlations of the epembryonic stages. These were referred to in his publications, but were not made as prominent as they deserved after the lectures at the Lowell Institute in 1849, and in his personal talks with his students or

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états analogues à ceux que présentent les espèces fossiles dans leur succession; ou en d'autres termes enfin, que le développement d'une classe dans l'histoire de la terre offre, à divers égards la plus grande analogie avec le développement d'un individu aux différentes époques de sa vie. La démonstration de cette vérité est un des plus beaux résultats de la paléontologie moderne."

These quotations antedate Louis Agassiz's direct statements since in his "Discours sur la Succession et le Développement des Êtres organisés à la Surface du Globe Terrestre," etc., Neuchatel, 1841, he does not give any embryological laws. It is of course quite possible that he did not consider it necessary to mention these in his "Discours," which, notwithstanding its title, was merely a general statement of the paleontological evidences of a plan in nature, and ended with an argument for the existence of an intelligent creator. Whether this was an omission, or that he did not at that time recognize the importance of the law of palingenesis, does not appear from the text of his publications. The first definite statement under Louis Agassiz's own hand appears to be in his "Recherches sur les Poissons Fossiles," Neuchatel, 1833–43, Vol. I. Chap. IV. p. 93: —

"J'aurai par conséquent souvent recours à l'embryologie d'une part pour rechercher les analogies entre le squelette des embryons et celui des poissons cartilagineux par rapport aux poissons osseux; d'autre part pour éclaircir les rapports qui existent entre les formes primitives que nous trouvons chez les poissons des anciennes couches de la terre, et celles qui se voient dans les premiers temps de la formation de l'embryon."

This was certainly written subsequently to the "Poissons d'Eau Douce," since Agassiz quotes Vogt upon the following pages 94, 95. He also speaks of the same on page 169, referring both to zoölogical rank and occurrence in time.

These are extracts from the Introduction, which was probably written and published in 1843, judging by the immediately following Preface to the first volume, which is dated 1843.

Vogt's candid admission in his Preface of constant consultations with his master, and his failure to state this law as his own discovery or to claim the authorship subsequently, lead one to think that it might not have originated with him.

Vogt fully understood the meaning and application of this law, and restates it clearly in his "Zoologische Briefe," Frankfurt am Main, 1851, p. 16, and also in his "Lehrbuch der Geologie und Petrefactenkunde," 1854, Vol. I. p. 471, and tries to apply it to the classification of different groups of the animal kingdom and to the history of their fossil remains in "Paleontologische Entwickelung," pp. 423–541. He seems to have been the first to have seen its true meaning as a law of evolution, since he completely rejects the doctrine of special creations. It may be that the only way out of this difficulty is to call this Agassiz and Vogt's law, just as it is now not infrequent to speak of Darwin's and Wallace's laws of natural selection.

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in his lectures I cannot remember that they were ever treated directly by anything more than incidental references, although embryology was very often the principal theme.

Nevertheless, I must have got directly from him, subsequently to 1858, the principles of this branch of research, and through this and the abundant materials furnished by the collections he had purchased and placed so freely at my disposal, I soon began to find that the correlations of the epembryonic stages and their use in studying the natural affinities of animals were practically an infinite field for work and discovery.

Although within a year after the beginning of my life as a student under Louis Agassiz I had become an evolutionist, this theoretical change of position altered in no essential way the conceptions I had at first received from him, nor the use we both made of them in classifying and arranging forms. This experience demonstrated to my mind the absurdity of disputing the claims of any author to the discovery of a series of facts and their correlations because of his misinterpretation of their more remote relations or general meaning. It is of some importance to notice this, because it is the rule now to attribute Von Baer's and his predecessors' and Louis Agassiz's discoveries in this line to Haeckel. This eminent author has, indeed, given one of the most modern definitions of this law, and has named it the 'law of biogenesis.' Haeckel's discoveries in embryology are sufficiently great without swelling the list with false entries, but it will probably be a long time before naturalists realize and acknowledge this error. Some of the most eminent embryologists in this country have adopted the Haeckelian nomenclature without sufficient critical examination of the term under discussion. The so called Haeckelian 'law of biogenesis' is really Agassiz's law of embryological recapitulation restated in the terms of evolution.

It has surprised me that serious objections to the use of the word 'biogenesis' in this connection have not been made. This word has been long employed in another sense, as antithetical to 'abiogenesis.' The latter has been for many years applied to the theory of the generation of living from inorganic matter, and the former to the theory asserting that living matter can originate only from living matter; the use of the phrase 'the law of biogenesis' is consequently inappropriate, since neither did Agassiz's nor Haeckel's discoveries cover so much ground. The former gave us a law for the correlations of the earlier stages of ontogeny with phylogeny. This cannot be called 'the law of biogenesis,' since that has been long ago stated as the law of the origin and continuity of organism, or, in other words, the genesis and continuity of

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life from and through living matter only. There are two different manifestations of Agassiz's law, which Haeckel defined and named 'palingenesis' and 'cœnogenesis,' the former referring to the ordinary or regular mode in which the characteristics of ancestors are repeated in the development of the individual, and the other to what is frequently called the abbreviated mode, etc.

These two modes are by no means all, but at present only the first or simplest manifestations of the phenomena need be treated of. This, or what Haeckel very appropriately calls 'palingenesis,' was what Louis Agassiz had studied, and, so far as all the essential facts were concerned, thoroughly understood, and it was this that he taught his students, so that it became, at any rate in my own case, the foundation of all my subsequent work in determining the mutual relations of forms. If then, as I have proposed in former publications, the term 'law of palingenesis' be adopted, this expressly states just what Louis Agassiz discovered.

Observations upon this ground made especially upon Cephalopoda have led to the discovery of correlations between the latter or epembryonic stages and the adult stages of extinct ancestors, which have greatly enlarged the field of application of Agassiz's law of palingenesis, and given it an exactitude that has made it of surpassing importance in the study of evolution. Beecher has been able to point out the single species of Brachiopod from which the whole of the vast number of distinct forms of this great group have originated. He has established this fact not only by showing that the young of the existing and fossil forms all repeat more or less at one stage the form of the adult of the initial species, but has also found a very near affine of this single ancestral species as a fossil appearing in one of the earliest of fossil-bearing formations.

Dr. R. T. Jackson has done the same work for the Aviculoids among the Pelecypoda, tracing all to one genus, *Nucula*, and has treated the Echinoidea in the same way, tracing them by the use of Agassiz's law to the genus *Bothriocidaris*.

Although the evidence is perhaps less conclusive with reference to the ancestor of Cephalopoda as a whole, this class has furnished the means of showing the action of this law in smaller groups with great accuracy. It has been possible to trace the origin of a number of smaller groups to single ancestors within the class by carefully studying the correlations of the epembryonic stages with the adults of the same group that have preceded them in time, and this study has also led to further discoveries. It has been found that the new characters were first introduced in the later stages of ontogeny, usually in the full-grown stage; then, as old age

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approached, certain losses of the characters of the adult took place, or, if additional growths were acquired, these were of a peculiar kind. These senile stages had been noticed by D'Orbigny and Quenstedt, but these authors did not attempt to show that any correlations existed between any stages of the ontogeny and the gradations occurring in the full-grown forms during their evolution in time, or what is called phylogeny. The oldest stage of the shell in Cephalopoda, Brachiopoda, and Pelecypoda is commonly marked by a series of retrogressive changes, which have been fully described elsewhere. These changes have a similar nature to those found in the old age of man, but they are more noticeable because they are recorded in the permanent characters of the hardened shell. The old man returns to second childhood in mind and body, and the shell of the cephalopod has in old age, however distinct and highly ornamented the adult, very close resemblance to its own young. This resemblance is a matter of form and aspect only, since there can be no close comparison in minute structure, nor functions between organs and parts, at these two different ends of life. Such analogies, however, have their own meaning, and are of great importance when properly translated.

In the first place they show that the cycle of life as manifested in man is found also in the ontogeny of other animals and more perfectly in proportion to the perfection of the record. They are consequently among shell-bearing animals, especially those that carry their embryonic shells and all their subsequent stages of development throughout their lives, more perfect, more decisive, as well as more obvious, than in animals, like the Vertebrata, which carry no such burden of hard dead parts, upon and in which their stages of development are recorded. The cycle of the ontogeny is, therefore, not only physiological, but it is also a definite series of structural changes and is often accompanied by transformations of remarkable and sometimes startling character.

These retrogressive transformations in old age of the shells of Cephalopoda, Brachiopoda, and Pelecypoda have been found to have decided correlations with the adult characters of species that appear simultaneously or later in time. If one traces any group through its evolution in time, it has, as stated by many authors, a period of rise called the epacme, a second period of greatest expansion in numbers of forms and species called the acme, and then usually a movement towards contraction called the paracme. All three of these terms were first proposed by Haeckel, who used them largely in a physiological or dynamical sense. The epacme of any group, large or small, is usually a process of evolu-

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tion by addition of new structures or characteristics based on older structures and thus leading to greater and greater complication of the primitive organization. The acme represents the time of greatest complication in structure and greatest expansion in numbers of forms for any group, large or small. The paracme is the decline, and this takes place through the reduction and actual loss of structures and characteristics that have been built up by evolution during the epacme. This is no ideal picture, but a simple statement of the experiences of those paleontologists who have patiently traced the history of groups through geologic time. Agassiz's law enables one to follow the epacme of the evolution of a species, or genus, or order, or larger group, but further correlations between the cycle of individual life and those in the evolution of its own genetic group must be sought in the correlations existing between the older retrogressive stages of the ontogeny and the paracme of each group.

The importance and peculiar nature of these correlations led me, in one of my papers, to introduce, for this branch of research, the term 'Bioplastology,' which will be found convenient by those interested in this class of work.

The following table of terms is useful here to explain the relations of the cycle of development in the individual to that of the group to which it belongs.

TERMS OF BIOPLASTOLOGY EXPLAINING THE CORRELATIONS BETWEEN STAGES OF THE ONTOGENY AND THOSE OF PHYLOGENY.

Ontogeny or Development.			*Phylogeny or Evolution of the Phylum.*		
Structural Conditions.	Stages.		Structural Conditions.	Stages.	Dynamical.
Anaplasis	Embryonic	Embryo or Fœtal	Phylanaplasis	Phylembryonic	
	Nepionic	Baby		Phylonepionic	Epacme
	Neanic	Adolescent		Phyloneanic	
Metaplasis	Ephebic	Adult	Phylometaplasis	Phylephebic	Acme
Paraplasis	Gerontic	Senile	Phyloparaplasis	Phylogerontic	Paracme

The dynamical terms are quoted from Haeckel, and were used by him to designate the phenomena of the rise and decline of types, and also the terms anaplasis and metaplasis. He, however, used 'cataplasis' in place of paraplasis, which is here preferred on account of the faulty derivation of cataplasis.

He realized the importance of these phenomena, and also the significance of the structural characteristics of decline, but did not trace out the distinct correlations which are claimed as fundamentals in bioplastology.

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The terms anaplasis, etc., and their correspondents, phylanaplasis, are the structural correlatives of dynamical terms, epacme, etc., and will be found useful when the statical phenomena or structures are mentioned or contrasted with the dynamical phenomena, or with periods of time in which they occur, since the terms epacme, acme, and paracme also refer to time. Terms of the ontogeny are placed opposite to their correlatives in the column of phylogenetic terms, but in reading the table it should be clearly understood that the individual whose life history is represented by the first three columns is supposed to have been taken from the midst of those that lived during the acme of the phylum and belonged to a phylephebic species. In studying the development of such an individual it has repeatedly been observed that the embryo repeated the adult characters of the most ancient representatives of the phylum, which are here called, in accordance with this evidence, phylembryonic.

It has also been ascertained that there are full-grown types in the epacme and acme of groups which correspond to the transient nepionic or baby stage of those that occur later in time; these are the phylonepionic; others have similar correspondences with the neanic stages, and are properly designated as phyloneanic types or forms. The structures of the ephebic (adult) stage are essentially the differentials of the time and fauna in which they occur, and necessarily have no correlations with the past. Their relations are obviously and wholly with the present, except in so far as they represent the consummations of evolution in structures. The structural changes in the gerontic stage of the individual are repeated with sufficient accuracy in the adult, and often even in the neanic stages of types that occur in the paracme of the evolution of a phylum, so that one is forced seriously to consider whether they may not have been inherited from types that occur at the acme of the same group. The fact that these changes occur first in the ontogeny during the gerontic stage does not necessarily imply that they first make their appearance after the reproductive period. No gerontic limit is known to the reproductive time in the lower animals, and it may well be that the continual recurrence of gerontic stages in individuals during the epacme of groups may lead to their finally becoming fixed tendencies of the stock or hereditary in the phylum, and thus established as one of the factors that occasion the retrogression or paracme of groups. The paracme may also be considered as occasioned by changes in the surroundings from favorable, as they must have been up to acmatic time, to unfavorable during the succeeding paracmatic period in evolution. Still a third supposition is also possible, namely, that the type, like the individual, has only a limited

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store of vitality, and both must progress and retrogress, complete a cycle and finally die out, in obedience to the same law.

All of these views can be well supported, but, whatever may be the true explanation, it is obvious that there are plenty of paracmatic types, which, in their full-grown and even in their neanic stages, correlate in characters and structures with the characters and structures that one first finds in the transient gerontic stages of acmatic forms of the same type. These can, therefore, be truthfully and accurately described as phylogerontic in the phylum.

In other words, one is able to apply gerontic changes in the ontogeny to the deciphering of the true relations, the arrangement and classification of forms occurring in the paracme, just as Agassiz's law of palingenesis can be used to explain the relations of the links in the chain of being forming the epacme of groups.

The cycle of the ontogeny is, therefore, the individual expression and abbreviated recapitulation of the cycle that occurs in the phylogeny of the same stock; and, while the embryonic, nepionic, and neanic stages give us, in abbreviated shape, the record of the epacme, the gerontic stages give, in a similar manner, the history of the paracme.

The difference between the nature of the two records is, however, necessarily as great as between the beginnings and the endings of existence. The successive stages of the individual are derived from the past, and simply point backwards along the track traversed by the phylum; the changes of the gerontic stage, on the other hand, point to the future, and are prophetic of what is to come in the decline of the type. The retrogressive decline of the individual and that of its type are along parallel lines, and the two are in direct correlation, so that the former becomes an abbreviated index of the latter.

One of the most useful results of these studies has been the method of work developed, the mode of study by series. To follow it out successfully, one must trace the terms of series from the first or most primitive grade to the last, through perhaps long periods of time, and, if upon the same level, through many gradations of structure.

The histologist or embryologist picks out a convenient form here and there for thorough investigation, but does not seem as yet to see the importance of the point of view here insisted upon, viz. that the only method of getting at the correlations of ontogeny and phylogeny is by following out the history of representative series of genetically connected embryos, and the same is true of the experimentalist. While, consequently, their results have been in the highest degree instructive and

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progressive along other lines of research, they throw no very strong light on the laws of evolution, and the best modern works on embryology, zoölogy, and experimentation neglect the only proper and efficient mode of studying one very important side of their subject.

One of the results of this mode of study has been the discovery of the law of acceleration in the inheritance of characters, or tachygenesis. Thus it has been found that characteristics are inherited in successive species or forms in a given stock at earlier and earlier stages in the ontogeny of each member of the series. These characteristics, as a rule, disappear from the ontogeny altogether in the terminal, or last occurring, members of a series, and terminal forms thus become very distinct in their development. This law I habitually illustrate as the crawling, walking, hopping, skipping, and jumping law.

Another result of this mode of study is the discovery that, in most genetic series, primitive forms exhibit much greater indifference to geologic changes, persist with comparatively unchanged structures through longer periods of time than those that occur at the acme of groups, and paracmatic forms, if widely distributed, are apt to be particularly short lived, and are very often narrowly localized in origin and duration. Primitive forms are also less changeable in their ontogeny; the adult differs less from either the young or the old than in acmatic forms. The same is true of phylogerontic forms; their old age and youth are less distinct from each other as stages than in acmatic forms. Primitive forms are less affected by gerontic changes in their ontogeny, that is, they have shorter old-age stages, than acmatic forms. Paracmatic forms have much longer old-age or gerontic stages than acmatic forms.

Lastly, it has been found that at the beginning of the evolution of any stock the progress was not only very rapid, but the departures in structures much more marked between the diverging lines of different species, genera, or families, and so on, than those that subsequently occurred in any one of these. This rapidity of expansion is also marvellously sudden in every series near its point of origin, and it is equally so in the whole animal kingdom, which appears with the larger proportion of all its principal divisions in the earliest known fossil-bearing rocks. Each series or type appears to have had a more or less free field, and its first steps in evolution were obviously not affected by natural selection. Subsequently, in the acme of the same series or type, the departures became less marked, and the divergences took place in less important structures; in other words, as stated above, the evolution is slower.

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On the other hand, after the acme is passed and the paracme sets in, there is a sensible quickening of evolution during decline.

Phylogerontic forms become more and more numerous, and there are wider departures in the structures from the acmatic forms than any of the divergences that occur within the acmatic forms themselves.

The hopping, skipping, and at last the jumping, begins in the extremes of the series, so that it becomes difficult, as has been shown by the author in a number of series, and by Cope when giving illustrations of the action of the law of tachygenesis, to connect one of these extreme forms with its nearest congeners.

The characters of the cycle in the ontogeny are here again similar to those of the phylogeny; thus the final substages of the gerontic stage are wider departures from the ephebic substages than these are among themselves and when compared with each other. The analogy of the old with the young shows this most conclusively, and the similarity of phylogerontic and phylonepionic forms in the same stock occurs in the phylogeny.

In fact, there is no end to the homological and analogical similarities and parallelisms of ontogeny and phylogeny wherever both are found complete.

There are types in which the ontogeny is incomplete, as among insects and other purely seasonal animals, and in these it becomes difficult, if not impracticable, to study the gerontic stages, and thus translate the phylogerontic types if they occur. These same types, and others also, present difficulties in their larval stages, owing to their indirect modes of development, which have been discussed by the author in "Insecta" and other publications, and need only be referred to here.

One of the bearings of these researches is of interest on account of the discussions between biologists, geologists, and mathematicians with regard to the length of time that life has existed on this planet, and the bearing of this upon calculations with regard to the age of the earth. It cannot be assumed that the time ratio was the same during the Eozoic or Pre-Paleozoic as during the Paleozoic or the Mesozoic, so far as the evolution of forms is concerned.

The author in other publications has claimed that this must have been the law, and explained the phenomena as parallel with that which takes place at the beginning of every series arising in the Paleozoic and Mesozoic, and also according to Minot's law of growth and other phenomena of the earlier stages in the ontogeny of every animal.

The evidence is very strong that great structural differences were evolved much more quickly in these early times, and the probabilities

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are that the progressive steps of the evolution of the primitive types of organisms took place with a rapidity unexampled in later ages. If the laws of bioplastology are true, the evolution of these forms must have occurred more quickly than those of their descendants, except some isolated phylogerontic types and phylopathic forms.* Man being the most remarkable of these phylogerontic types, we can at once realize what this statement means. If his remains in all their vastness were a part of geological history, and could be contemplated separated from the artificial halo of idealism, it would be seen that they were the direct results of the law of tachygenesis acting upon the basis of a simian organization and exceptional, as compared with other phylogeronts only because of this exceptional basis.

All inferences with reference to the length of time that life has existed upon the earth are consequently defective, since, as far as known to the author, they do not take into consideration this law of variable proportions of time in evolution of organisms at different stages in their history.

* The phrase 'evolution by saltation' has been used for the sudden appearance of divergent types by several authors, first by Dr. W. H. Dall; but this seems to me to be simply a mode of expressing a general fact, or series of facts that occur everywhere, and in all series more or less through the action of the law of tachygenesis.

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STANDING VOTES.

1. Communications of which notice had been given to the Secretary shall take precedence of those not so notified.

2. Resident Fellows who have paid all fees and dues chargeable to them are entitled to receive one copy of each volume or article printed by the Academy, on application to the Librarian personally or by written order, within two years from the date of publication. And the current issues of the Proceedings shall be supplied, when ready for publication, free of charge, to all the Fellows and members of the Academy who desire to receive them.

3. The Committee of Publication shall fix from time to time the price at which the publications of the Academy may be sold. But members may be supplied at half this price with volumes which they are not entitled to receive free, and which are needed to complete their sets.

4. Two hundred extra copies of each paper accepted for publication in the Memoirs or Proceedings of the Academy shall be placed at the disposal of the author, free of charge.

5. Resident Fellows may borrow and have out from the Library six volumes at any one time, and may retain the same for three months, and no longer.

6. Upon special application, and for adequate reasons assigned, the Librarian may permit a larger number of volumes, not exceeding twelve, to be drawn from the Library for a limited period.

7. Works published in numbers, when unbound, shall not be taken from the Hall of the Academy, except by special leave of the Librarian.

8. Books, publications, or apparatus shall be procured from the income of the Rumford Fund only on the certificate of the Rumford Committee that they, in their opinion, will best facilitate and encourage the making of discoveries and improvements which may merit the Rumford Premium.

9. The Annual Meeting and the other stated meetings shall be holden at eight o'clock, P. M.

10. A meeting for receiving and discussing scientific communications may be held on the second Wednesday of each month not appointed for stated meetings, excepting July, August, and September.

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4. Foreign Honorary Members shall be chosen only after a nomination made at a meeting of the Council, signed at the time by at least seven of its members, and read at a stated meeting previous to that on which the balloting takes place.

5. Three fourths of the ballots cast must be affirmative, and the number of affirmative ballots must amount to eleven to effect an election of Fellows or Foreign Honorary Members.

6. Each Section of the Academy is empowered to present lists of persons deemed best qualified to fill vacancies occurring in the number of Foreign Honorary Members or Associate Fellows allotted to it; and such lists, after being read at a stated meeting, shall be referred to the Council for Nomination.

7. If, in the opinion of a majority of the entire Council, any Fellow — Resident or Associate — shall have rendered himself unworthy of a place in the Academy, the Council shall recommend to the Academy the termination of his Fellowship; and provided that a majority of two thirds of the Fellows at a stated meeting, consisting of not less than fifty Fellows, shall adopt this recommendation, his name shall be stricken off the roll of Fellows.

CHAPTER XI.

Of Amendments of the Statutes.

1. All proposed alterations of the Statutes, or additions to them, shall be referred to a committee, and, on their report at a subsequent meeting, shall require for enactment a majority of two thirds of the members present, and at least eighteen affirmative votes.

2. Standing Votes may be passed, amended, or rescinded, at any stated meeting, by a majority of two thirds of the members present. They may be suspended by a unanimous vote.

CHAPTER XII.

Of Literary Performances.

1. The Academy will not express its judgment on literary or scientific memoirs or performances submitted to it, or included in its publications.

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CHAPTER X.

Of the Election of Fellows and Honorary Members.

1. Elections shall be made by ballot, and only at stated meetings.

2. Candidates for election as Resident Fellows must be proposed by two or more Resident Fellows, in a recommendation signed by them, specifying the Section to which the nomination is made, which recommendation shall be transmitted to the Corresponding Secretary, and by him referred to the Council for Nomination. No person recommended shall be reported by the Council as a candidate for election, unless he shall have received a written approval, signed at a meeting of the Council by at least seven of its members. All nominations thus approved shall be read to the Academy at a stated meeting, and shall then stand on the nomination list during the interval between two stated meetings, and until the balloting. No person shall be elected a Resident Fellow, unless he shall have been resident in this Commonwealth one year next preceding his election. If any person elected a Resident Fellow shall neglect for one year to pay his admission fee, his election shall be void; and if any Resident Fellow shall neglect to pay his annual assessments for two years, provided that his attention shall have been called to this article, he shall be deemed to have abandoned his Fellowship; but it shall be in the power of the Treasurer, with the consent of the Council, to dispense (*sub silentio*) with the payment both of the admission fee and of the assessments, whenever in any special instance he shall think it advisable so to do.

3. The nomination of Associate Fellows shall take place in the manner prescribed in reference to Resident Fellows; and after such nomination shall have been publicly read at a stated meeting previous to that when the balloting takes place, it shall be referred to the Council for Nomination; and a written approval, authorized and signed at a meeting of said Council by at least seven of its members, shall be requisite to entitle the candidate to be balloted for. The Council may in like manner originate nominations of Associate Fellows, which must be read at a stated meeting previous to the election, and be exposed on the nomination list during the interval.

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4. Every person who takes a book from the Library shall give a receipt for the same to the Librarian or his assistant.

5. Every book shall be returned in good order, regard being had to the necessary wear of the book with good usage. And if any book shall be lost or injured, the person to whom it stands charged shall replace it by a new volume or set, if it belongs to a set, or pay the current price of the volume or set to the Librarian; and thereupon the remainder of the set, if the volume belonged to a set, shall be delivered to the person so paying for the same.

6. All books shall be returned to the Library for examination at least one week before the Annual Meeting.

CHAPTER IX.

Of Meetings.

1. There shall be annually four stated meetings of the Academy; namely, on the second Wednesday in May (the Annual Meeting), on the second Wednesday in October, on the second Wednesday in January, and on the second Wednesday in March. At these meetings only, or at meetings adjourned from these and regularly notified, shall appropriations of money be made, or alterations of the statutes or standing votes of the Academy be effected.

2. Fifteen Fellows shall constitute a quorum for the transaction of business at a stated meeting. Seven Fellows shall be sufficient to constitute a meeting for scientific communications and discussions.

3. The Recording Secretary shall notify the meetings of the Academy to each Fellow residing in Boston and the vicinity; and he may cause the meetings to be advertised, whenever he deems such further notice to be needful.

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CHAPTER VII.

Of the Treasurer.

1. The Treasurer shall give such security for the trust reposed in him as the Academy shall require.

2. He shall receive officially all moneys due or payable, and all bequests or donations made to the Academy, and by order of the President or presiding officer shall pay such sums as the Academy may direct. He shall keep an account of all receipts and expenditures; shall submit his accounts to the Auditing Committee; and shall report the same at the expiration of his term of office.

3. The Treasurer shall keep a separate account of the income and appropriation of the Rumford Fund, and report the same annually.

4. All moneys which there shall not be present occasion to expend shall be invested by the Treasurer, under the direction of the Finance Committee, on such securities as the Academy shall direct.

CHAPTER VIII.

Of the Librarian and Library.

1. It shall be the duty of the Librarian to take charge of the books, to keep a correct catalogue of same, and to provide for the delivery of books from the Library. He shall also have the custody of the publications of the Academy.

2. The Librarian, in conjunction with the Committee on the Library, shall have authority to expend, as they may deem expedient, such sums as may be appropriated, either from the Rumford or the General Fund of the Academy, for the purchase of books, and for defraying other necessary expenses connected with the Library. They shall have authority to propose rules and regulations concerning the circulation, return, and safe-keeping of books; and to appoint such agents for these purposes as they may think necessary.

3. To all books in the Library procured from the income of the Rumford Fund, the Librarian shall cause a stamp or label to be affixed, expressing the fact that they were so procured.

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whom the printing of memoirs accepted for publication shall be intrusted.

6. The Committee on the Library, of three Fellows, who shall examine the Library, and make an annual report on its condition and management.

7. An Auditing Committee, of two Fellows, for auditing the accounts of the Treasurer.

CHAPTER VI.

Of the Secretaries.

1. The Corresponding Secretary shall conduct the correspondence of the Academy, recording or making an entry of all letters written in its name, and preserving on file all letters which are received; and at each meeting he shall present the letters which have been addressed to the Academy since the last meeting. With the advice and consent of the President, he may effect exchanges with other scientific associations, and also distribute copies of the publications of the Academy among the Associate Fellows and Foreign Honorary Members, as shall be deemed expedient; making a report of his proceedings at the Annual Meeting. Under the direction of the Council for Nomination, he shall keep a list of the Fellows, Associate Fellows, and Foreign Honorary Members, arranged in their Classes and in Sections in respect to the special sciences in which they are severally proficient; and he shall act as secretary to the Council.

2. The Recording Secretary shall have charge of the Charter and Statute-book, journals, and all literary papers belonging to the Academy. He shall record the proceedings of the Academy at its meetings; and after each meeting is duly opened, he shall read the record of the preceding meeting. He shall notify the meetings of the Academy, and apprise committees of their appointment. He shall post up in the Hall a list of the persons nominated for election into the Academy; and when any individual is chosen, he shall insert in the record the names of the Fellows by whom he was nominated.

3. The two Secretaries, with the Chairman of the Committee of Publication, shall have authority to publish such of the proceedings of the Academy as as may seem to them calculated to promote the interests of science.

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Academy. Length of continuous membership in the Academy shall determine the seniority of the Vice-Presidents.

2. The President, or, in his absence, the next officer as above enumerated, is empowered to draw upon the Treasurer for such sums of money as the Academy shall direct. Bills presented on account of the Library, or the Publications of the Academy, must be previously approved by the respective committees on these departments.

3. The President, or, in his absence, the next officer as above enumerated, shall nominate members to serve on the different committees of the Academy which are not chosen by ballot.

4. Any deed or writing to which the common seal is to be affixed shall be signed and sealed by the President, when thereto authorized by the Academy.

CHAPTER V.

Of Standing Committees.

1. At the Annual Meeting there shall be chosen the following Standing Committees, to serve for the year ensuing, viz.: —

2. The Committee of Finance, to consist of the President, Treasurer, and one Fellow chosen by ballot, who shall have charge of the investment and management of the funds and trusts of the Academy. The general appropriations for the expenditures of the Academy shall be moved by this Committee at the Annual Meeting, and all special appropriations from the general and publication funds shall be referred to or proposed by this Committee.

3. The Rumford Committee, of seven Fellows, to be chosen by ballot, who shall consider and report on all applications and claims for the Rumford Premium, also on all appropriations from the income of the Rumford Fund, and generally see to the due and proper execution of this trust.

4. The C. M. Warren Committee, of seven Fellows, to be chosen by ballot, who shall consider and report on all applications for appropriations from the income of the C. M. Warren Fund, and generally see to the due and proper execution of this trust.

5. The Committee of Publication, of three Fellows, to whom all memoirs submitted to the Academy shall be referred, and to

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CHAPTER III.

Of Nominations of Officers.

1. At the stated meeting in March, the President shall appoint from the next retiring Councillors a Nominating Committee of three Fellows, one for each class.

2. It shall be the duty of this Nominating Committee to prepare a list of candidates for the offices of President, Vice-Presidents, Corresponding Secretary, Recording Secretary, Treasurer, Librarian, Councillors, and the Standing Committees which are chosen by ballot; and to cause this list to be sent by mail to all the Resident Fellows of the Academy not later than four weeks before the Annual Meeting.

3. Independent nominations for any office, signed by at least five Resident Fellows and received by the Recording Secretary not less than ten days before the Annual Meeting, shall be inserted in the call for the Annual Meeting, which shall then be issued not later than one week before that meeting.

4. The Recording Secretary shall prepare for use, in voting at the Annual Meeting, a ballot containing the names of all persons nominated for office under the conditions given above.

5. When an office is to be filled at any other time than at the Annual Meeting, the President shall appoint a Nominating Committee, in accordance with the provisions of Section 1, which shall announce its nomination in the manner prescribed in Section 2 at least two weeks before the time of election. Independent nominations, signed by at least five Resident Fellows and received by the Recording Secretary not later than one week before the meeting for election, shall be inserted in the call for that meeting.

CHAPTER IV.

Of the President.

1. It shall be the duty of the President, and, in his absence, of the senior Vice-President present, or next officer in order as above enumerated, to preside at the meetings of the Academy; to summon extraordinary meetings, upon any urgent occasion; and to execute or see to the execution of the Statutes of the

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3. Fellows residing out of the State of Massachusetts shall be known and distinguished as Associate Fellows. They shall not be liable to the payment of any fees or annual dues, but on removing within the State shall be admitted to the privileges,* and be subject to the obligations, of Resident Fellows. The number of Associate Fellows shall not exceed *one hundred*, of whom there shall not be more than *forty* in either of the three Classes of the Academy.

4. The number of Foreign Honorary Members shall not exceed *seventy-five;* and they shall be chosen from among persons most eminent in foreign countries for their discoveries and attainments in either of the three departments of knowledge above enumerated. And there shall not be more than *thirty* Foreign Members in either of these departments.

CHAPTER II.

Of Officers.

1. There shall be a President, three Vice-Presidents, one for each Class, a Corresponding Secretary, a Recording Secretary, a Treasurer, and a Librarian, which officers shall be annually elected, by ballot, at the Annual Meeting, on the second Wednesday in May.

2. At the same time, and in the same manner, nine Councillors shall be elected, three from each Class of the Academy, but the same Fellows shall not be eligible on more than three successive years. These nine Councillors, with the President, the three Vice-Presidents, the two Secretaries, the Treasurer, and the Librarian, shall constitute the Council. It shall be the duty of this Council to exercise a discreet supervision over all nominations and elections. With the consent of the Fellow interested, they shall have power to make transfers between the several Sections of the same Class, reporting their action to the Academy.

3. If any office shall become vacant during the year, the vacancy shall be filled by a new election, and at the next stated meeting, or at a meeting called for this purpose.

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* Associate Fellows may attend, but cannot vote, at meetings of the Academy. See Chapter I. 2.

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STATUTES AND STANDING VOTES.

STATUTES.

Adopted May 30, 1854: *amended September* 8, 1857, *November* 12, 1862, *May* 24, 1864, *November* 9, 1870, *May* 27, 1873, *January* 26, 1876, *June* 16, 1886, *October* 8, 1890, *January* 11 *and May* 10, 1893, *April* 11, *May* 9, *and October* 10, 1894, *and March* 13, *April* 10, *and May* 8, 1895.

CHAPTER I.

Of Fellows and Foreign Honorary Members.

1. The Academy consists of *Fellows* and *Foreign Honorary Members*. They are arranged in three Classes, according to the Arts and Sciences in which they are severally proficient, viz.: Class I. The Mathematical and Physical Sciences; — Class II. The Natural and Physiological Sciences; — Class III. The Moral and Political Sciences. Each Class is divided into four Sections, viz.: Class I., Section 1. Mathematics and Astronomy; — Section 2. Physics; — Section 3. Chemistry; — Section 4. Technology and Engineering. Class II., Section 1. Geology, Mineralogy, and Physics of the Globe; — Section 2. Botany; — Section 3. Zoölogy and Physiology; — Section 4. Medicine and Surgery. Class III., Section 1. Philosophy and Jurisprudence; — Section 2. Philology and Archæology; — Section 3. Political Economy and History; — Section 4. Literature and the Fine Arts.

2. Fellows, resident in the State of Massachusetts, only, may vote at the meetings of the Academy.* Each Resident Fellow shall pay an admission fee of ten dollars and such annual assessment, not exceeding ten dollars, as shall be voted by the Academy at each Annual Meeting.

* The number of Resident Fellows is limited by the Charter to 200.

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SECTION III. — 8.

Zoölogy and Physiology.

Michael Foster,	Cambridge.
Carl Gegenbauer,	Heidelberg.
Ludimar Hermann,	Königsberg.
Albrecht Kölliker,	Würzburg.
A. Kovalevskij,	St. Petersburg.
Lacaze-Duthiers,	Paris.
Rudolph Leuckart,	Leipsic.
J. J. S. Steenstrup,	Copenhagen.

SECTION IV. — 4.

Medicine and Surgery.

W. Kühne,	Heidelberg.
Lord Lister,	London.
Sir James Paget, Bart.,	London.
Rudolph Virchow,	Berlin.

CLASS III. — *Moral and Political Sciences.* — 20.

SECTION I. — 3.

Philosophy and Jurisprudence.

James Martineau,	London.
Sir Frederick Pollock,	Oxford.
Henry Sidgwick,	Cambridge.

SECTION II. — 7.

Philology and Archæology.

Ingram Bywater,	Oxford.
Sir John Evans,	Hemel Hempstead.
Pascual de Gayangos,	Madrid.
J. W. A. Kirchhoff,	Berlin.
G. C. C. Maspero,	Paris.
Max Müller,	Oxford.
Karl Weinhold,	Berlin.

SECTION III. — 7.

Political Economy and History.

Duc de Broglie,	Paris.
James Bryce,	Oxford.
W. Dörpfeld,	Athens.
W. E. Gladstone,	Hawarden.
Hermann Grimm,	Berlin.
Theodor Mommsen,	Berlin.
William Stubbs,	Oxford.

SECTION IV. — 3.

Literature and the Fine Arts.

Jean Léon Gérôme,	Paris.
John Ruskin,	Coniston.
Leslie Stephen,	London.

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FOREIGN HONORARY MEMBERS. — 65.

(Number limited to seventy-five. Elected as vacancies occur.)

Class I. — *Mathematical and Physical Sciences.* — 22.

Section I. — 7.

Mathematics and Astronomy.

Arthur Auwers,	Berlin.
Francesco Brioschi,	Milan.
H. A. E. A. Faye,	Paris.
Charles Hermite,	Paris.
William Huggins,	London.
Otto Struve,	Karlsruhe.
H. C. Vogel,	Potsdam.

Section II. — 4.

Physics.

Boltzmann,	Vienna.
A. Cornu,	Paris.
Lord Rayleigh,	Witham.
Sir G. G. Stokes, Bart.,	Cambridge.

Section III. — 8.

Chemistry.

Adolf Baeyer,	Munich.
Marcellin Berthelot,	Paris.
Robert Bunsen,	Heidelberg.
J. H. van't Hoff,	Amsterdam.
Mendeleeff,	St. Petersburg.
Victor Meyer,	Heidelberg.
Sir H. E. Roscoe,	London.
Julius Thomsen,	Copenhagen.

Section IV. — 3.

Technology and Engineering.

Sir Henry Bessemer,	London.
Lord Kelvin,	Glasgow.
Maurice Lévy,	Paris.

Class II. — *Natural and Physiological Sciences.* — 23.

Section I. — 5.

Geology, Mineralogy, and Physics of the Globe.

Alfred Des Cloizeaux,	Paris.
A. E. Nordenskiöld,	Stockholm.
C. F. Rammelsberg,	Berlin.
Henry C. Sorby,	Sheffield.
Heinrich Wild,	Zurich.

Section II. — 6.

Botany.

J. G. Agardh,	Lund.
E. Bornet,	Paris.
Sir Joseph D. Hooker,	Sunningdale.
W. Pfeffer,	Leipsic.
Solms-Laubach,	Strasburg.
Eduard Strasburger,	Bonn.

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SECTION II. — 3.

Botany.

A. W. Chapman,	Apalachicola, Fla.
W. Trelease,	St. Louis.
John D. Smith,	Baltimore.

SECTION III. — 6.

Zoölogy and Physiology.

Joel A. Allen,	New York.
W. K. Brooks,	Baltimore.
O. C. Marsh,	New Haven.
S. Weir Mitchell,	Philadelphia.
A. S. Packard,	Providence.
A. E. Verrill,	New Haven.

SECTION IV. — 7.

Medicine and Surgery.

John S. Billings,	New York.
Jacob M. Da Costa,	Philadelphia.
W. A. Hammond,	New York.
William Osler,	Baltimore.
Alfred Stillé,	Philadelphia.
Wm. H. Welch,	Baltimore.
H. C. Wood,	Philadelphia.

CLASS III. — *Moral and Political Sciences.* — 29.

SECTION I. — 5.

Philosophy and Jurisprudence.

T. M. Cooley,	Ann Arbor, Mich.
D. R. Goodwin,	Philadelphia.
Charles S. Peirce,	New York.
T. R. Pynchon,	Hartford, Conn.
Jeremiah Smith,	Cambridge.

SECTION II. — 7.

Philology and Archæology.

A. N. Arnold,	Pawtuxet, R.I.
Timothy Dwight,	New Haven.
B. L. Gildersleeve,	Baltimore.
D. C. Gilman,	Baltimore.
T. R. Lounsbury,	New Haven.
E. E. Salisbury,	New Haven.
A. D. White,	Ithaca, N.Y.

SECTION III. — 9.

Political Economy and History.

Henry Adams,	Washington.
G. P. Fisher,	New Haven.
M. F. Force,	Cincinnati.
H. E. von Holst,	Chicago.
Henry C. Lea,	Philadelphia.
Edward J. Phelps,	Burlington, Vt.
W. G. Sumner,	New Haven.
J. H. Trumbull,	Hartford, Conn.
David A. Wells,	Norwich, Conn.

SECTION IV. — 8.

Literature and the Fine Arts.

James B. Angell,	Ann Arbor, Mich.
L. P. di Cesnola,	New York.
F. E. Church,	New York.
H. H. Furness,	Philadelphia.
R. S. Greenough,	Florence.
Augustus St. Gaudens,	New York.
E. C. Stedman,	Bronxville, N.Y.
W. R. Ware,	New York.

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ASSOCIATE FELLOWS. — 96.

(Number limited to one hundred. Elected as vacancies occur.)

CLASS I. — *Mathematical and Physical Sciences.* — 36.

SECTION I. — 15.

Mathematics and Astronomy.

Edward E. Barnard,	Chicago.
S. W. Burnham,	Chicago.
George Davidson,	San Francisco.
Fabian Franklin,	Baltimore.
Asaph Hall,	Washington.
George W. Hill,	Washington.
E. S. Holden,	Mt. Hamilton, Cal.
James E. Keeler,	Allegheny, Pa.
Emory McClintock,	New York.
Simon Newcomb,	Washington.
Charles L. Poor,	Baltimore.
William A. Rogers,	Waterville, Me.
George M. Searle,	Washington.
J. N. Stockwell,	Cleveland, O.
Chas. A. Young,	Princeton, N.J.

SECTION II. — 7.

Physics.

Carl Barus,	Providence, R.I.
J. Willard Gibbs,	New Haven.
S. P. Langley,	Washington.
A. M. Mayer,	Hoboken, N. J.
A. A. Michelson,	Chicago.
Ogden N. Rood,	New York.
H. A. Rowland,	Baltimore.

SECTION III. — 7.

Chemistry.

Wolcott Gibbs,	Newport, R.I.
Frank A. Gooch,	New Haven.
S. W. Johnson,	New Haven.
J. W. Mallet,	Charlottesville, Va.
E. W. Morley,	Cleveland, O.
J. M. Ordway,	New Orleans.
Ira Remsen,	Baltimore.

SECTION IV. — 7.

Technology and Engineering.

Henry L. Abbot,	New York.
Cyrus B. Comstock,	Washington.
W. P. Craighill,	Washington.
F. R. Hutton,	New York.
George S. Morison,	Chicago.
William Sellers,	Philadelphia.
Robt. S. Woodward,	New York.

CLASS II. — *Natural and Physiological Sciences.* — 31.

SECTION I. — 15.

Geology, Mineralogy, and Physics of the Globe.

Cleveland Abbe,	Washington.
George J. Brush,	New Haven.
Edward S. Dana,	New Haven.
Walter G. Davis,	Cordova, Arg.
Sir J. W. Dawson,	Montreal.
G. K. Gilbert,	Washington.
James Hall,	Albany, N.Y.
Clarence King,	New York.
Joseph LeConte,	Berkeley, Cal.
J. Peter Lesley,	Philadelphia.
S. L. Penfield,	New Haven.
J. W. Powell,	Washington.
R. Pumpelly,	Newport, R.I.
A. R. C. Selwyn,	Ottawa.
G. C. Swallow,	Columbia, Mo.

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SECTION IV. — 11.

Literature and the Fine Arts.

Francis Bartlett,	Boston.
John Bartlett,	Cambridge.
George S. Boutwell,	Groton.
J. Elliot Cabot,	Brookline.
T. W. Higginson,	Cambridge.
S. R. Koehler,	Boston.
Charles G. Loring,	Boston.
Percival Lowell,	Brookline.
Charles Eliot Norton,	Cambridge.
Horace E. Scudder,	Cambridge.
Barrett Wendell,	Boston.

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SECTION IV. — 15.

Medicine and Surgery.

Samuel L. Abbot,	Boston.
Edward H. Bradford,	Boston.
Arthur T. Cabot,	Boston.
David W. Cheever,	Boston.
Frank W. Draper,	Boston.
Thomas Dwight,	Boston.
Reginald H. Fitz,	Boston.
Charles F. Folsom,	Boston.
Frederick I. Knight,	Boston.
Francis Minot,	Hyde Park.
Samuel J. Mixter,	Boston.
W. L. Richardson,	Boston.
Theobald Smith,	Boston.
Henry P. Walcott,	Cambridge.
John C. Warren,	Boston.

CLASS III. — *Moral and Political Sciences.* — 57.

SECTION I. — 9.

Philosophy and Jurisprudence.

James B. Ames,	Cambridge.
Charles C. Everett,	Cambridge.
Horace Gray,	Boston.
John C. Gray,	Boston.
G. Stanley Hall,	Worcester.
Nathaniel Holmes,	Cambridge.
John E. Hudson,	Boston.
Josiah Royce,	Cambridge.
James B. Thayer,	Cambridge.

SECTION II. — 21.

Philology and Archæology.

William S. Appleton,	Boston.
Charles P. Bowditch,	Boston.
Lucien Carr,	Cambridge.
Franklin Carter,	Williamstown.
Joseph T. Clarke,	Boston.
Henry G. Denny,	Boston.
Epes S. Dixwell,	Cambridge.
William Everett,	Quincy.
William W. Goodwin,	Cambridge.
Henry W. Haynes,	Boston.
David G. Lyon,	Cambridge.
Bennett H. Nash,	Boston.
Frederick W. Putnam,	Cambridge.
Edward Robinson,	Boston.
F. B. Stephenson,	Boston.
Joseph H. Thayer,	Cambridge.
Crawford H. Toy,	Cambridge.
John W. White,	Cambridge.
Justin Winsor,	Cambridge.
John H. Wright,	Cambridge.
Edward J. Young,	Waltham.

SECTION III. — 16.

Political Economy and History.

Charles F. Adams,	Lincoln.
Edward Atkinson,	Boston.
Mellen Chamberlain,	Chelsea.
John Cummings,	Woburn.
Andrew M. Davis,	Cambridge.
Charles F. Dunbar,	Cambridge.
Samuel Eliot,	Boston.
John Fiske,	Cambridge.
A. C. Goodell, Jr.,	Salem.
Henry C. Lodge,	Nahant.
A. Lawrence Lowell,	Boston.
Augustus Lowell,	Boston.
John C. Ropes,	Boston.
Denman W. Ross,	Cambridge.
Charles C. Smith,	Boston.
F. W. Taussig,	Cambridge.

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Henry M. Howe,	Boston.
Charles L. Jackson,	Cambridge.
Walter L. Jennings,	Worcester.
Leonard P. Kinnicutt,	Worcester.
Charles F. Mabery,	Cleveland, O.
Arthur Michael,	Boston.
George D. Moore,	Worcester.
Charles E. Munroe,	Washington.
John U. Nef,	Chicago.
Robert H. Richards,	Boston.
Theodore W. Richards,	Cambridge.
Charles R. Sanger,	St. Louis.
Stephen P. Sharples,	Cambridge.
Francis H. Storer,	Boston.
Charles H. Wing,	Ledger, N. C.
Edward S. Wood,	Boston.

SECTION IV. — 13.

Technology and Engineering.

Eliot C. Clarke,	Boston.
Gaetano Lanza,	Boston.
E. D. Leavitt,	Cambridgeport.
William R. Livermore,	Boston.
Hiram F. Mills,	Lowell.
Cecil H. Peabody,	Boston.
Alfred P. Rockwell,	Manchester.
Andrew H. Russell,	Rock Island, Ill.
Peter Schwamb,	Arlington.
Charles S. Storrow,	Boston.
George F. Swain,	Boston.
William Watson,	Boston.
Morrill Wyman,	Cambridge.

CLASS II. — *Natural and Physiological Sciences.* — 63.

SECTION I. — 13.

Geology, Mineralogy, and Physics of the Globe.

H. H. Clayton,	Milton.
Algernon Coolidge,	Boston.
William O. Crosby,	Boston.
William M. Davis,	Cambridge.
Benj. K. Emerson,	Amherst.
O. W. Huntington,	Cambridge.
Robert T. Jackson,	Boston.
Jules Marcou,	Cambridge.
William H. Niles,	Cambridge.
John E. Pillsbury,	Boston.
Nathaniel S. Shaler,	Cambridge.
Warren Upham,	St. Paul, Minn.
John E. Wolff,	Cambridge.

SECTION II. — 9.

Botany.

William G. Farlow,	Cambridge.
Charles E. Faxon,	Boston.
George L. Goodale,	Cambridge.
H. H. Hunnewell,	Wellesley.
B. L. Robinson,	Cambridge.
Charles S. Sargent,	Brookline.
Arthur B. Seymour,	Cambridge.
Charles J. Sprague,	Boston.
Roland Thaxter,	Cambridge.

SECTION III. — 26.

Zoölogy and Physiology.

Alexander Agassiz,	Cambridge.
Robert Amory,	Boston.
James M. Barnard,	Milton.
Henry P. Bowditch,	Boston.
William Brewster,	Cambridge.
Louis Cabot,	Brookline.
Samuel F. Clarke,	Williamstown.
W. T. Councilman,	Boston.
Charles B. Davenport,	Cambridge.
Harold C. Ernst,	Boston.
Charles H. Fernald,	Amherst.
J. Walter Fewkes,	Boston.
Edward G. Gardiner,	Boston.
Samuel Henshaw,	Cambridge.
Alpheus Hyatt,	Cambridge.
John S. Kingsley,	Somerville.
Theodore Lyman,	Brookline.
Edward L. Mark,	Cambridge.
Charles S. Minot,	Boston.
Edward S. Morse,	Salem.
George H. Parker,	Cambridge.
James J. Putnam,	Boston.
Samuel H. Scudder,	Cambridge.
William T. Sedgwick,	Boston.
James C. White,	Boston.
William M. Woodworth,	Cambridge.

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LIST

OF THE

FELLOWS AND FOREIGN HONORARY MEMBERS.

(Corrected to June 1, 1897.)

RESIDENT FELLOWS. — 195.

(Number limited to two hundred.)

Class I. — *Mathematical and Physical Sciences.* — 75.

Section I. — 17.

Mathematics and Astronomy.

Solon I. Bailey,	Arequipa, Peru.
Seth C. Chandler,	Cambridge.
Alvan G. Clark,	Cambridgeport.
J. Rayner Edmands,	Cambridge.
Francis M. Green,	Boston.
Gustavus Hay,	Boston.
Henry Mitchell,	Boston.
Edward C. Pickering,	Cambridge.
John Ritchie, Jr.,	Boston.
John D. Runkle,	Brookline.
T. H. Safford,	Williamstown.
Edwin F. Sawyer,	Brighton.
Arthur Searle,	Cambridge.
William E. Story,	Worcester.
Henry Taber,	Worcester.
O. C. Wendell,	Cambridge.
P. S. Yendell,	Dorchester.

Section II. — 23.

Physics.

A. Graham Bell,	Washington.
Clarence J. Blake,	Boston.
Francis Blake,	Weston.
John H. Blake,	Boston.
Charles R. Cross,	Boston.
Amos E. Dolbear,	Somerville.
H. M. Goodwin,	Boston.
Edwin H. Hall,	Cambridge.
Hammond V. Hayes,	Cambridge.
Silas W. Holman,	Boston.
William L. Hooper,	Somerville.
William W. Jacques,	Newton.
Alonzo S. Kimball,	Worcester.
Frank A. Laws,	Boston.
T. C. Mendenhall,	Worcester.
Benjamin O. Peirce,	Cambridge.
A. Lawrence Rotch,	Boston.
Wallace C. Sabine,	Cambridge.
John S. Stone,	Boston.
Elihu Thomson,	Lynn.
John Trowbridge,	Cambridge.
A. G. Webster,	Worcester.
Robert W. Willson,	Cambridge.

Section III. — 22.

Chemistry.

Samuel Cabot,	Boston.
Arthur M. Comey,	Cambridge.
Thos. M. Drown,	So. Bethlehem, Pa.
Charles W. Eliot,	Cambridge.
Thomas Gaffield,	Boston.
Henry B. Hill,	Cambridge.

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this can be given than his remarkable utterance, prefacing the sixth volume of the "Astronomical Journal," on the occasion of its temporary suspension by the war in 1861: "There is but one mode of laboring for Cisatlantic science to-day, namely, by struggling for the maintenance of civilization against barbarism in the Western Hemisphere. And this leaves little opportunity for astronomical research. Those who may not fight against armed treason may at least assume the burdens of those who do."

Dr. Gould married, in 1861, Mary Apthorp Quincy, daughter of the Hon. Josiah Quincy. She died in 1883. Never was there a nobler example of a wife's self-sacrifice than hers, in the endurance of privation and self-imposed exile, the severance of family and social ties, for the purpose of making possible the accomplishment of a husband's life-work.

Dr. Gould died on Thanksgiving day, November 26, 1896. His memory and achievements are a precious heritage to his country and his science.

SETH C. CHANDLER.

The Academy has received an accession of one Resident Fellow, one Associate Fellow, and three Foreign Honorary Members.

The roll of the Academy, corrected to date, includes the names of one hundred and ninety-three Resident Fellows, ninety-three Associate Fellows, and sixty-six Foreign Honorary Members.

MAY 12, 1897.

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claim than had yet been accorded to it; and that a journal worthily supporting the dignity of a pure science would have very great influence upon its future progress. Accordingly, without ostentation, he established the "Astronomical Journal" in November, 1849, offering it to the use of astronomers, for the publication exclusively of original investigations. He edited and supported it until, at the end of the sixth volume, in 1861, its issue was suspended, first by the war for the preservation of the Union, afterward by his absence in Cordoba. A long nurtured hope was realized when he was enabled, in 1885, to resume its publication, and to continue it, at the rate of nearly one volume annually, to the present time. Of all the great enterprises of his life, this is the one which he has most cherished. With careful forethought, he has made due provision for its continuance.

Dr. Gould took a deep interest in the work of the International Committee of Weights and Measures, of which he was a most influential member. He represented both the United States and the Argentine Republic on that Committee, and was a constant attendant upon its annual conferences in Paris. He was President of the American Metrological Society and of the Colonial Society of Massachusetts from their inception. He was one of the original charter members of the National Academy of Sciences, and has been a member of the American Academy of Arts and Sciences since 1847, and one of its Vice-Presidents since 1895. He received the degree of Ph. D. from Göttingen in 1848, and that of LL. D. from Harvard in 1885, and from Columbia in 1887. During his illustrious career he was the recipient of the highest honors that Europe has to bestow, to an extent scarcely vouchsafed to any other American. A few only will be named here. Mem. Roy. Soc. (London): For. Assoc. Roy. Astr. Soc. (London): Cor. Mem. Acad. Sci. (Institut de France): Acad. Imp. Sci. (St. Petersburg): Kön. Akad. Wiss. (Berlin): Kön. Ges. Wiss. (Göttingen): Kais. Akad. Wiss. (Vienna): Bur. d. Long. (Paris). He was also knighted, of the Order Pour le Mérite, by Prussia.

Dr. Gould came, on both paternal and maternal sides, of old Colonial stock. The interest which he took throughout life in genealogy and the history of the early founders of New England was the outcome, not so much, perhaps, of pride of ancestry, as it was of his intense patriotism, which was one of his most marked characteristics. Next to the sacred domestic ties and the innumerable personal friendships which he so tenderly cherished, even before his devotion to his beloved science, came his affection for and pride in his country. No more vivid exemplification of

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which were the original and always the dominant object of the enterprise, were begun in 1872, substantially completed in 1877, and revised in 1882–83. This work was embodied in the Zone Catalogues, containing 73,160 stars, which appeared in 1884. Parallel with this, and almost overshadowing it in importance, was carried on the independent series of meridian-circle observations for the General Catalogue of 32,448 stars, completed in 1885. Dr. Gould, besides, left the manuscript of the remainder of his series of fifteen volumes, not then published, — containing the observations and the annual catalogues, incorporated in the General Catalogue, — complete to the minutest detail, ready for the printer. These have since appeared, from time to time, — the last volume, rounding out his work, reaching Cambridge but a few hours before his death.

Another part of the work for the Cordoba Observatory, planned by Dr. Gould as a fitting extension of it, was a "Durchmusterung" of the southern sky. For this, indeed, he had provided the instrumental means and trained the assistants, it being his purpose to be ready to begin it at any time in case of any unforeseen delay or accident to the other work. On leaving Cordoba he confided it to the care of Dr. Thome, by whom, with Mr. Tucker, it has been so worthily conducted.

Dr. Gould also established, under the auspices of the Argentine government, a meteorological service, second in extent, it is believed, only to that of the United States. Upon leaving South America he intrusted this charge to the hands of his worthy successor, Walter G. Davis.

The earliest to recognize and demonstrate the capabilities of photography to render service to the astronomy of precision, Dr. Gould, by his experience with the Rutherfurd plates of the Pleiades and the Præsepe, was incited to arrange to carry forward at Cordoba, on an extensive scale, a similar work upon the southern stellar clusters. His other labors there were so onerous that he confined his attention to securing plates suitable for precise measurement. Of these he accumulated about 1400, and brought them home with him for measurement and reduction. Without permitting himself a well earned retirement, he turned at once, tirelessly, to this labor, which has been the principal occupation of the last ten years of his life. This is substantially complete, and will be given to the world as it came from his hand.

Dr. Gould had an enthusiasm for the advancement of his beloved science far wider than the limits of what he could by personal investigation accomplish. Early in his career he keenly realized that astronomy had reached a stage of development in America which entitled it to a higher

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the United States Naval Observatory since its establishment, as he had done also, several years previously, for the expedition to Chili to determine the solar parallax. In 1866 he planned and executed the work of establishing, by the Atlantic cable, the relation in longitude between European and American stations, involving, as a part, interesting researches on the velocity of the galvanic current in submarine cables, similar to those he had already made on land-lines. As actuary of the United States Sanitary Commission, he conducted, and published in a large volume, extensive and important researches upon Military and Anthropological Statistics and the Distribution of Population. About the same time he undertook the reduction of Rutherfurd's photographs of the Pleiades. The results, partially published in 1866, were submitted completely, in an elaborate memoir, to the National Academy in 1870, together with a second memoir on the Præsepe. He was, indeed, a pioneer in the utilization of photography for exact astronomical measurement. About 1864 he built an observatory in Cambridge, equipped with an eight-foot transit instrument, and, until 1867, carried on a determination of the right ascensions of all the stars to the tenth magnitude within one degree of the pole. The work was completely reduced, but the discussion and publication were postponed by his removal to Cordoba.

In 1865 he became intensely impressed with a desire to explore the southern celestial hemisphere. The opportunity to do so soon came. This project assumed at first the form of a private astronomical expedition, for which his friends in Boston had promised the pecuniary means; but, under the enthusiastic support of Mr. Sarmiento, at first as Argentine Minister to this country, and later as President of that republic, it rapidly broadened, and finally led to the establishment by Dr. Gould of a permanent National Observatory at Cordoba. This marks an epoch in modern astronomy, the equalization of our knowledge of the two celestial hemispheres. The institution and its work form an impressive monument to his memory.

It is impossible, in brief space, to describe or characterize the marvellous work here undertaken and so faultlessly pushed to completion by Dr. Gould, during the fifteen years of self-imposed exile from his native land, with unfaltering devotion and energy, in the face of difficulty and domestic bereavement. The work on the uranography of the southern heavens was finished in 1874, and was published under the title of the "Uranometria Argentina," which will remain a classic for all time. The zone observations of the stars between 23° and 80° south declination,

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From this point Dr. Gould's life became one of incessant activity, impressing its mark in many ways upon the intellectual life of the community; but the line of intensest force naturally took the direction of his own beloved science, to which he communicated an impulse not measured merely by what he accomplished for it by his direct investigations, great as that is, but also by the force which always emanates from so earnest a nature. He inspired a new breath into American astronomy. The new atmosphere which he brought with him from Germany, where he had caught the spirit of the great masters under whom he studied, became gradually transfused upon this side the sea. His enthusiasm for the introduction of better means and methods of research was caught by his compatriots, their courage to regenerate our science was sustained, and transmitted through various channels to the next and to the present generation. Thus we may say without fear of being controverted that American astronomy to-day is a different thing from what it would have been without Gould's predominant influence, deep and quiet but strong, to upbuild it and to free it from the clumsiness and imperfections which still impede it, even in some of the otherwise most enlightened nations of the world. It is under his leadership that American astronomy has climbed to where it looks with steady and level eye upon that of Germany, which occupies perhaps a larger, but not a loftier plane.

Let us now glance at Dr. Gould's more prominent labors, passing by his earlier important investigations in applied theoretical and in practical astronomy, as well as his numerous and valuable contributions to the literature of science, education, and other departments of thought, which we find scattered through the long range of his career. In 1852 he was appointed to take charge of the longitude determinations of the Coast Survey. He organized, developed, and extended this service, retiring in 1867. Meanwhile, in 1855, he became director of the Dudley Observatory in Albany, equipped and organized the institution, and carried it on without remuneration and at his private expense. He left it in 1859, after a severe struggle to preserve the institution for purposes of scientific investigation.

In 1859 he published his discussion of the places and proper motions of circumpolar stars, for use as standards in the Coast Survey. These, as revised by him in 1861, together with his similar list of clock-stars, were adopted as the standards for the American Ephemeris, and, as to the circumpolars, remain in such use to this day. In 1866 he published his reduction of D'Agelet's observations. About the same time he performed a similar service for the greater part of the observations made at

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BENJAMIN APTHORP GOULD.

Benjamin Apthorp Gould was born on September 27, 1824, at No. 5 Winthrop Place, Boston. The years of his preparatory education were passed at the Chauncy Hall and Boston Latin Schools. He graduated from Harvard College in 1844. It is interesting to note, as evidence of his wonderful versatility of mind, and in view of the subsequent choice of a career which has made his name so illustrious in the annals of science, that, although he attained in college high distinction in mathematical and physical branches, the earliest studies of his predilection were classical rather than scientific. After leaving college he took charge of the Boston Latin School. At the end of a year, however, his intellectual energies took their final direction towards science. What were the springs of the influence which turned him to astronomy, and how long the impulse had been gathering force, cannot now be told, but the passionate devotion with which he entered upon this career, and the tenacity with which he held to it, — at times under circumstances of extreme discouragement which never caused him to falter or swerve from his purpose, — are characteristic of the man. This initial decision of a young man of twenty-one, as we look back upon it from a point where we can measure the results that have flowed from it, seems not so much an episode in an individual career as an epoch in our national scientific history. For the date, July, 1845, when Gould placed his foot upon the steamer from Boston, with the avowed and definite purpose to devote himself to a life purely of scientific research, marks quite distinctly a most important phase in American astronomy. Up to that time the instance of a man doing this as his only earthly aim, while unassured of a professor's chair or other similar appointment, and not as a means of livelihood, was in this country absolutely unknown. With a steadiness of purpose singular in so young a man, he pursued diligently the opportunity he had himself created, for three years at the fountain-heads of astronomical learning. Beginning his life of preparation, study, and work with Airy at Greenwich, he then went to Paris. But it was afterwards, in Germany, that he secured his true education in the regenerated methods of modern astronomical research; at Berlin, where he spent a year with Encke; at Altona, Pulkowa, and Gotha, under Peters, Struve, and Hansen; and at Göttingen, where for a year he was a pupil of Gauss, and where he took his Doctorate of Philosophy at the University in 1848. He then returned home, full of early honors and flushed with lofty hopes and honorable ambitions.

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in others his name gave weight to organizations in which he was not called upon for active effort. The number and variety of the appointments thus showered upon him marked not only the unbounded range of his own interests, but the confidence of others that every appeal to public spirit would stir his heart.

The bibliography of his written work, prepared at the Institute of Technology and revised with great care since his death, will be found in the Publications of the American Statistical Society for June, 1897. It is a remarkable record of intellectual activity, maintained for nearly forty years, and resulting in a series of important contributions to the thought of his time, — a manifold claim to eminence in the world of science and letters.

A complete list of the honorary degrees and other marks of distinction conferred upon General Walker by public bodies, at home and abroad, cannot be undertaken here. It is enough to say that he was made Doctor of Laws by Amherst, Columbia, Dublin, Edinburgh, Harvard, St. Andrews, and Yale, and Doctor of Philosophy by Amherst and Halle; that he was a member, regular or honorary, of the National Academy of Sciences, the Philosophical Society of Washington, the Massachusetts Historical Society and this Academy, of the Royal Statistical Society of London, the Royal Statistical Society of Belgium, the Statistical Society of Paris, the French Institute, and the International Statistical Institute; and that he was an officer of the French Legion of Honor.

General Walker was endowed by nature with peculiar gifts for a career of distinction. In any company of men he instantly drew attention by his solid erect form and dignified presence, by his deep and glowing eye, and by his dark features, cheerful, often mirthful, always alive. His instant command of his intellectual resources gave him the confidence needed for a leading place, and his friendly bearing, strong judgment, and easy optimism made others welcome his leadership. His convictions were deep, and his opinions, once formed, were shaken with difficulty, for in discussion he had the soldier's quality of not knowing when he is beaten. His ambition was strong, and he liked to feel the current of sympathy and approval bearing him on, but he did not shrink from his course if others refused to follow. From first to last, he grappled with large undertakings and large subjects, conscious of powers which promised him the mastery. Such as his contemporaries saw him he will live for the future reader in many a sentence and page, — cheerful, courageous, hopeful.

CHARLES F. DUNBAR.

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General Walker's election to the Presidency of the Massachusetts Institute of Technology, in 1881, placed him at the head of an institution badly in need of a vigorous, confident, and many-sided administrator, for the development of its great possibilities. The plan on which it should work had been prepared and its foundations laid broad and deep by President Rogers, but the work itself was still languishing, endowment and equipment were scanty, and the number of students declining. General Walker's administration was signalized by a sudden revival of the school. Funds were secured, new buildings were built, the confidence of the public won, and at General Walker's death the school of barely two hundred students, still maintaining the severe standard of work set by its founder, had upon its register nearly twelve hundred students and maintained a staff of one hundred and thirty professors and instructors of different grades. Of the qualities as an educator and administrator of a great technical school displayed by General Walker in this brilliant part of his career, a striking description, made from close observation, has been given by Professor H. W. Tyler of the Faculty of the Institute, in the Educational Review for June, 1897.

There was doubtless much in the circumstances attending the foundation of the Institute of Technology which any disinterested friend of scientific education must now regret. But time has healed wounds and removed jealousies which divided a former generation, and none can now be found to question either the practical or the scientific value of the great institution conceived by Rogers, and brought to its present deserved eminence under the successor of whose day he lived to see little more than the dawn.

At no period of General Walker's life did he fail to take an active interest in the work of the community in which he lived. That he was already charged with great responsibilities was a reason, both with his fellow citizens and with himself, for increasing the load. An early instance of this was his service as Commissioner of Indian Affairs for one year while still in charge of the census of 1870, — a service marked by an annual report remarkable for its thorough review of the whole subject, and by the appearance of his book, "The Indian Question" (1874). At different times, in New Haven and in Boston, he was a member of the local School Board and of the State Board of Education. He was a Trustee of the Boston Public Library and of the Museum of Fine Arts, one of the Boston Park Commissioners, and an almost prescriptive member of any more temporary board or committee. In some of these capacities his labors have left their traces in his written works,

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President, in his absence; and he wisely took his place at its head, with the conviction that its purposes were better than the statement made of them, and that the membership of the new organization gave promise of good results for economic science. Under his administration, which lasted until 1892, the basis of the Association was broadened, all appearance of any test of scientific faith disappeared, and American economists found themselves associated in catholic brotherhood. In part this change was no doubt due to the marked subsidence of the debate as to the deductive and the historical methods, but in part also it was due to the good judgment, personal influence, and perhaps in some instances the persuasive efforts of the President, who thus rendered no small service to economic science.

Which of General Walker's contributions to economic theory are likely to have lasting value, is a question not yet ready for decision. The subjects to which he specially devoted his efforts are still under discussion. His theory of distribution is not yet established as the true solution of the great problem; the wages fund has not yet ceased to be controversial matter; it is not yet settled whether the advocates or the opponents of bimetallism are to triumph in the great debate of this generation. But whether as a theoretical writer he is to hold his present place or to lose it, there can be no question as to the importance of his work, in imparting stimulus and the feeling of reality to all economic discussions in which he had a part. His varied experience and wide acquaintance with men had made him in a large sense a man of affairs. He watched the great movements of the world, not only in their broad relations, but as they concern individuals. He was apt to treat economic tendencies, therefore, not only in their abstract form, but also as facts making for the happiness or the injury of living men. Economic law was reasoned upon by him in much the same way as by others, but he never lost his vivid perception of the realities among which the law must work out its consequences. In his pages, therefore, theory seemed to many to be a more practical matter and nearer to actual life than it is made to appear by most economists. His words seemed to carry more authority, his illustrations to give more light, the whole science to become a lively exposition of the trend and the side movements of a world of passion and effort. A great English economist has said that Walker's explanation of the services rendered by the *entrepreneur* remind one of passages of Adam Smith. A great service has been rendered to the community by the writer who, in our day, has been able thus to command attention to political economy as a discussion belonging to the actual world.

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appeared in the midst of a heated Presidential canvass, in which the issues had taken such form that some, who like himself were supporters of "sound money," found a jarring note in what they regarded as needless concessions to "free silver," and in the sharp phrase in which his ardor and deep conviction sometimes found expression. But the book was not written for effect upon an election; it was the last stroke of a soldier, in a world-wide battle, — soon to lay aside his arms.

It was General Walker's good fortune to enter the field as an economist when the study of economics was gaining new strength in the United States from the powerful stimulus of the Civil War, and of the period of rapid material development and change which followed. The revision of all accepted theories which set in did not displease him, and he took his share in the ensuing controversies, whether raised by himself or others, with equal zest. His own tendency, however, was towards a rational conservatism, and his modes of thought never ceased to show the influence of writers, French and English, of whom he appeared to the superficial observer to be the severe critic. "A Ricardian of the Ricardians" he styled himself in his Harvard lectures on land, published under the title of "Land and its Rent" (1883). His theory of distribution, if enunciated by one of narrower sympathies than himself, might have been thought to be designed as a justification of the existing order of things. In his monetary discussions he contended for a return to what he deemed the safe ways of the past. As for his view of the future, in a public address in 1890, after a remarkable passage describing the sea of agitation and debate which had submerged the entire domain of economics, and threatened to sweep away every landmark of accepted belief, he said, "I have little doubt that in due time, when these angry floods subside, the green land will emerge, fairer and richer for the inundation, but not greatly altered in aspect or in shape."

The election of General Walker as the first President of the American Economic Association, in recognition of his acknowledged eminence, deserves a passing notice at this point. The Association was organized at Saratoga in 1885, under circumstances which threatened to make it the representative of a school of economists rather than of the great body of economic students in America, and with a dangerous approach to something like a scientific creed. General Walker cannot be said to have represented any particular school. He was both theorist and observer, the framer of a theory of distribution, and also an industrious student of past and current history. By a happy choice the new Association strengthened its claim upon public attention by electing him its

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vancing reputation of its author. Public opinion in the United States was in extreme confusion on the questions involved in the return to specie payment; there was a formidable agitation for the repeal of the Resumption Act, and Congress was entering upon its long series of efforts to rehabilitate silver as a money metal. At this juncture, when every part of the theory of money was the subject of warm discussion, scientific and popular alike, General Walker, using the substance of a course of lectures delivered by him in the Johns Hopkins University in 1877, laid before the public an elaborate and broad-minded survey of the whole field, claiming little originality for his work, but giving material help in concentrating upon scientific lines a discussion which was wandering in endless vagaries. On the general subject his views had no doubt been formed early, under the influence of his father, to whom, in more than one passage of this book, he makes touching allusion, and later in life he found in them little to change, although the long *régime* of paper money and its consequences suggested many things to be added. In 1879 he published, under the title of "Money in its Relations to Trade and Industry," what was in some sense an abridgment of the larger work, made for use in a course of lectures in the Lowell Institute; and in his "Political Economy" he again condensed his arguments and conclusions as to money, as part of his discussion of the grand division, Exchange.

When the International Monetary Conference met in 1878, by invitation of the United States, General Walker went to Paris as one of the commissioners for this country. His discussion of bimetallism had not been carried in "Money" much beyond a careful statement of the question and of the arguments on each side, but it was carried far enough to show that international bimetallism, and not the simple remonetization of silver by the United States, was, in his view, the proper method of securing what he deemed an adequate supply of money for this country and for the commercial world. Great emphasis was laid, in "Money, Trade, and Industry," upon the necessity for "concerted action by the civilized states," and this ground was consistently held by him until his share in the discussion ended with the publication of "International Bimetallism" (1896), a few months before his death. In this book, which was the outcome of a course of lectures delivered in Harvard University, after reviewing the controversy over silver, which had more and more engaged his attention as time went on, he declared more vigorously than ever his opinion of the futility of the policy of solitary action, adopted by the United States in the Act of 1878. "International Bimetallism"

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of Amherst College, July 8, 1874, and he further developed the subject in an article contributed to the North American Review for January, 1875. Few books in political economy have taken a place in the foreground of scientific discussion more quickly than "The Wages Question." Many economists followed the author's lead with little delay, and those who were slower to admit that the object of his attack was in fact the wages fund of the older school, recoguized his assault as by far the most serious yet made. Unquestionably it compelled an immediate review of a large body of thought by the great mass of economic students in the English speaking countries.

In "The Wages Question," General Walker drew the line clearly between the function of the capitalist and that of the employer, or *entrepreneur*, and between interest, which is the return made to the former, and profits, which are the reward of the latter. It was however in his "Political Economy" (1883), that he worked out his theory of the source of business profits and of the law governing the returns secured by the employing class. This enabled him to lay down a general theory of distribution, to be substituted for that associated with the wages fund theory, which he regarded as completely exploded, and indeed "exanimate." Of the four parties to the distribution of the product of industry, three, the owner of land, the capitalist, and the employer, in his view, receive shares which are determined, respectively, by the law of Ricardo, by the prevailing rate of interest, and by a law of business profits analogous to the law of rent. These shares being settled, each by a limiting principle of its own, labor becomes the "residual claimant," be the residue more or less, and any increase of product resulting from the energy, economy, or care of the laborors "goes to them by purely natural laws, provided only competition be full and free." So too the gains from invention enure to their benefit, except so far as the law may interfere by creating a monopoly. This striking solution of the chief problem of economics attracted wide attention, and was further expounded and defended by its author in the discussions which it provoked, as may be seen by reference to the earlier volumes of the Quarterly Journal of Economics. Indeed, in his last published work, "International Bimetallism" (page 283), he prefaces a statement of his theory by saying, "I have given no small part of my strength during the past twenty years to the advocacy of that economic view which makes the laborer the residual claimant upon the product of industry."

General Walker published his treatise, "Money" (1878), at a moment singularly opportune for the usefulness of the book and the ad-

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ment, in order to secure the improved service and economy of a trained force of moderate size, constantly employed. Upon an office thus organized could be laid, at the regular intervals, the duty of collecting and preparing the returns of population and of agriculture for the decennial census required by the Constitution, and perhaps for an intermediate fifth year enumeration, and also in the intervals the systematic prosecution of other statistical investigations, to be charged upon the office from time to time as occasion might require.

General Walker's appointment as Professor in the Sheffield Scientific School, in 1872, carried him beyond the boundary of statistics into the general field of political economy. His training for this extended range of work, although obtained by a less systematic process than is now usual, had begun early, and as opportunity offered was carried on effectively. In one of his prefaces, he remarks that he began writing for the press upon money in 1858, probably having in mind a series of letters to the National Era of Washington, beginning soon after the crisis of 1857, and continued for some months, noticeable for sharply defined views on the subjects of banking and currency, and also as to the merits of Mr. Henry C. Carey as an economist. In 1865, before going to Williston Seminary, he lectured upon political economy for a short time at Amherst in his father's absence, and in 1866 his father recognized with pride his important assistance in finishing the "Science of Wealth." From the close of the war, he is otherwise known to have been a keen student of economics, although a student under such limitations and so hampered by pressing occupations as to make it difficult for him to do equal justice to all parts of his outfit. It was perhaps from this cause, in part, that his earliest important publications as an economist were two treatises on widely separated topics, "The Wages Question" and "Money."

The earlier of these two books, "The Wages Question" (1876), instantly attracted the attention both of economists and of the general public by its lively and strong discussion of the central topic of the day, then more commonly treated either as a matter of dry theory, or as a problem to be settled by sentiment. Following Longe and Thornton, the author made an unsparing attack upon the wages fund theory, and, arguing that wages are paid from the product of labor and not from accumulated capital, he set forth with great vigor the influences which affect the competition between laborer and employer in the division of this product. General Walker's earliest public statement of his now familiar opinions touching the wages fund, and the payment of wages from the product, was made, it is believed, in an address delivered before the literary societies

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Colored Race in the United States," he used his freedom from official relations in exposing the mischief done by legislative failure to provide intelligently for an important public service. As a whole, however, the Census of 1870 was the best and the most varied in its scope that had yet been obtained for the United States. It was, after all, a signal proof of what can be done by a competent head, even with imperfect legislation, and established the reputation of the Superintendent as an administrative officer, at the same time that his fresh and vigorous discussion of results secured him high rank among statistical writers. Great interest was excited, moreover, by the remarkable use made of the graphic method in presenting the leading results of this census, in his "Statistical Atlas of the United States" (1874).

The Act providing for the Census of 1880 was greatly modified, by General Walker's advice, and the working force was for the first time organized upon an intelligent system, by the employment of specially selected enumerators in place of the subordinates of the United States marshals, to whom the law had previously intrusted the collection of returns. Highly qualified experts were also employed for the historical and descriptive treatment of different industries and interests, as demanded by the monumental character of the centennial census. Various causes delayed the completion of this gigantic undertaking. Those to whom a census is merely a compendious statement of passing facts became impatient at the slow issue of the twenty-two stately quartos, and complained that the work was on such a scale as to be obsolescent before its appearance. General Walker, in an article in the Quarterly Journal of Economics for April, 1888, explained some of the special causes of the delay in publication and took upon himself perhaps an undue share of responsibility for the difficulties caused by an original underestimate of the total cost of the census. But notwithstanding its misfortunes, the Census of 1880 is a great work of enduring value and not excessive cost, — great in its breadth of design, worthy of the nation and of the epoch, and a lasting monument of the power of its Superintendent to conceive and to execute. Following the Census of 1870, it won for him universal recognition as one of the leading statisticians of his time.

In the article to which reference has just been made, General Walker, in his discussion of future arrangements for the national census, offered as the fruits of his own experience some valuable suggestions, which deserve more attention than they have yet received. It is hardly necessary, however, to enter upon them here, except to recall the fact that he advised the organization of the Census Office as a permanent establish-

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United States; in 1871 he was appointed Commissioner of Indian Affairs; in 1872 he was made Professor of Political Economy and History in the Sheffield Scientific School of Yale College; in 1876 he was Chief of the Bureau of Awards for the Centennial Exposition in Philadelphia; in 1878 he was sent as a Commissioner for the United States to the International Monetary Conference at Paris; in 1879 he was appointed Superintendent of the Tenth Census of the United States; in 1881 he was made President of the Massachusetts Institute of Technology; in 1882 he was elected President of the American Statistical Association; in 1885 he was elected first President of the American Economic Association; in 1891 he was elected Vice-President of the National Academy of Sciences; in 1893 he was President-adjunct of the International Statistical Institute, at its session in Chicago.

General Walker's successive appointments as Superintendent of the Census of 1870 and of that of 1880 were the direct result of the energy and skill with which, during the months of his service in the Bureau of Statistics, he had effected the reorganization of that office and its work. The opportunities given to him as a statistician, by having charge of these two censuses, were of a remarkable kind. The census of 1870, being the first taken after the Civil War, was for that reason by far the most interesting and important since 1790. It was to show the social and economic changes wrought by four years of prodigal expenditure both of life and of resources, and by the unparalleled revolution in the industrial organization of the former slave States. It was also to ascertain and record the conditions under which the nation entered upon a new and wonderful stage of its material growth. The census of 1880 was the unique occasion for what General Walker designed as a "grand monumental exhibit of the resources, the industries, and the social state of the American people,' made approximately at the close of a century of national independence.

The Census of 1870, to the great regret of all who had any scientific interest in the subject, was left by Congress to be taken under the provisions of the Census Act of 1850, by persons neither selected nor controlled by the Census Office. In the still disturbed condition of some of the Southern States, the work was thus thrown into the hands of men notoriously unfit for such employment, and the returns, especially of the black population, were vitiated at their source. In his Report of 1872, and in his Introduction to the "Compendium of the Census of 1880," General Walker described in strong language the difficulties which thus beset the work in 1870; and again in the Publications of the American Statistical Association for December, 1890, writing upon the "Statistics of the

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General Couch. From that time he was upon duty with the Army of the Potomac, serving with advancing rank upon the staff of Generals Warren and Hancock through some of the severest campaigns of the war. He resigned his commission in January, 1865, from illness contracted while a prisoner within the Confederate lines, received the brevet rank of Brigadier General "for distinguished service and good conduct," and returned to civil life bearing the honorable scars of the brave. It afterwards fell to his lot, in his "History of the Second Army Corps" (1886), and his "Life of General Hancock" (1894), to write the narrative of events no small part of which had passed before his eyes. Little of his own history is to be found in those glowing pages, but every line bears witness to the intense enthusiasm with which he never failed to kindle when he recalled his army life, and to his devotion to the great captains under whom he served.

Like many other young men, who, as soldiers in the War for the Union, drank the wine of life early, General Walker came home with his character matured, his capacities developed, his intellectual forces aroused and trained, — a man older than his years. The career in which he was to win new distinction did not open for him at once upon the sudden return of peace. For three years he was a teacher of the classics in Williston Seminary, and in 1868, being compelled by an attack of quinsy to seek a change of occupation, he became an assistant of Mr. Samuel Bowles, editor of the Springfield Republican. From this place he was drawn into the public service at Washington, by the agency of Mr. David A. Wells, who was then Special Commissioner of the Revenue, and in search of a new Chief for the Bureau of Statistics. The work of the Bureau had fallen into some discredit, and was far in arrears, and the inability of the former Chief of the Bureau to command the confidence of Congress seriously embarrassed the continuance of an important work. By Mr. Wells's advice General Walker was made Deputy Special Commissioner and placed in charge of the Bureau, and a new career was at once opened before him, for which he was fitted in a peculiar manner both by his intellectual interests and his administrative capacity. The Bureau was reorganized and its reputation was regained. The monthly publications were resumed, and soon showed that progressive improvement which has made them one of the most valuable repositories in existence for the study of the commercial and financial activity of a great country.

From his appointment to the charge of the Bureau of Statistics the steps in General Walker's new career followed in rapid succession. In 1870 he was appointed Superintendent of the Ninth Census of the

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has afforded the writer more pleasure than the privilege, in association with Mr. A. W. Grabau, of giving the name of our friend to the glacial lake which once adorned that region, and was a controlling factor in the development of the surface geology. Mr. Bouvé lived long enough to note the general and cordial acceptance of this name; and I venture to hope that it may long endure as a fitting memorial of this earliest and most devoted student of the geology of the district which embraces Lake Bouvé.

W. O. Crosby.

FRANCIS AMASA WALKER.

Francis Amasa Walker, late President of the Massachusetts Institute of Technology, and a Fellow of this Academy from October, 1882, was born in Boston, July 2, 1840, and died of apoplexy in that city, January 5, 1897.

His father, the late Amasa Walker of North Brookfield, was a well known figure in the political life of Massachusetts for many years. He was a leader in the Free Soil movement of 1848, and in the subsequently combined opposition to the Whig party. He served in each branch of the Legislature, was for two years Secretary of the Commonwealth, was a Presidential Elector in 1860, and a member of the lower House of Congress for the session of 1862–63. From 1842 to 1848 he lectured on political economy in Oberlin College, and was afterwards a frequent writer for periodicals, especially upon topics connected with finance and banking, in which he also showed special interest when in Congress. From 1859 to 1869 he was Lecturer upon Political Economy in Amherst College, publishing during that time his well known book, the "Science of Wealth," and died in 1875.

Francis Amasa Walker, the son, thus grew up with an inherited predilection and aptitude for economic study, strengthened by the associations of boyhood and youth. When he graduated from Amherst College in 1860, however, his first step was to enter as a student of law the office of Charles Devens and George F. Hoar of Worcester, — both gentlemen destined, like himself, soon to attain national reputation. On the breaking out of the Civil War in 1861, Mr. Devens at first took the field as an officer of militia, and, when later he raised the Fifteenth Regiment of Massachusetts Infantry in Worcester County, young Walker enlisted and was mustered into the service as Sergeant Major, August 1, 1861. Ten days later, he was commissioned and assigned to the staff of

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nearly of the same density as not to be readily and certainly distinguished by careful weighing.

Mr. Bouvé's later contributions to scientific literature relate chiefly to the geology of the Boston Basin, and especially of the South Shore. These papers include: (1.) "The Genesis of the Boston Basin and its Rock Formations," in which for the first time the importance of the antecedent chemical decay of the older rocks in explaining the origin of the conglomerates and slates is adequately recognized. (2.) "The Indian Potholes or Giant's Kettles of Foreign Writers," a carefully illustrated and in every way admirable account of the most interesting group of glacial potholes yet discovered in this region. (3.) The chapter on the geology of Hingham, prepared for the town history. This was by far his most important study, and it was my good fortune to be intimately associated with him in this work, which extended over a period of half a dozen years.

I have never found field-work more enjoyable or profitable; and, as in the Museum, I was deeply impressed by Mr. Bouvé's unselfish singleness of purpose, his high appreciation of the educational value of the local geology, and his painstaking thoroughness. He labored, not for fame, but for the advancement of the community in which he lived. He never counted time or strength while there seemed to be any possibility of verifying a fact or testing a conclusion; and in this contribution to the town history he realized in gratifying measure his ideal, which was not merely to set forth the geologic structure of the town, but to show his fellow townspeople that in its geological history Hingham is in a large degree an epitome of the world, and that within the narrow limits of the town are presented problems as stupendous and full of interest as any that have ever engaged the attention of geologists.

The part of this work relating to the surface geology or drift phenomena was subsequently amplified and published as a separate paper in in the Proceedings of the Natural History Society. Not content with giving to Hingham and the world the intellectual results of his labors, Mr. Bouvé placed in the town library, as an additional stimulus to interest in the local geology, a well selected and carefully labelled series of the Hingham rocks. To these he subsequently added the main part of his extensive collection of minerals. The arrangement and labelling of this generous gift to the town, almost his last public work, was frequently interrupted by his failing health; and he experienced no little satisfaction in not being obliged to leave it unfinished.

Nothing connected with his work on the geology of the South Shore

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again the next day and the next, for half an hour or an hour in the morning and as long as daylight lasted in the afternoon, making this work, which he loved so well and called his recreation, a part of his daily routine. Thus month by month, without haste or faltering, important and enduring results were accomplished.

Although specially interested, as his published papers and the records show, in several branches of natural history, Mr. Bouvé's first love among the natural sciences was mineralogy. In the mineralogical annals of the Society three names are especially prominent, — Francis Alger, Charles T. Jackson, and Thomas T. Bouvé. These three men were contemporaries and lifelong friends; and each in his own way contributed in an important degree to the development of this department of the Museum. Mr. Bouvé was the youngest of the trio, and the period of his activity extended well into the modern era in the history of educational methods. He was thus led to a deeper appreciation of the value of minerals as a factor in elementary education. It is therefore probably well within bounds to say, that for this reason, and because of his greater length of service, Mr. Bouvé has done more than any other one man to make this collection what it is to-day, an important adjunct of the educational system of the community.

During the years when we worked together upon the minerals, I had the pleasure of hearing from his lips the history, both in general and in detail, of a large part of the collection; and whether the specimens had been collected by himself or a fellow member, or obtained by purchase or exchange, his evident love for them made me feel that I was being introduced to his dear friends, whose care he was reluctant to relinquish to another.

His appreciation of the beautiful in minerals culminated in his well known fondness for gems; and these he did not value commercially, but only in proportion to their intrinsic beauty and scientific interest. This study forced upon his attention the unsatisfactory nature of the criteria, such as color and lustre, commonly relied upon in the identification of cut stones; and led him to test more thoroughly than had been done before the relatively fundamental property of specific gravity. In his valuable paper on this subject he demonstrated to the satisfaction of Professor Dana, and other high authorities, that while each of the mineral species to which the gems belong varies notably in specific gravity, so that the several species overlap and are indistinguishable by this character, the gems, being in every instance the purest and most ideal forms of their respective species, are essentially constant, and only rarely so

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After serving the Society efficiently in almost every subordinate capacity, he was, in 1870, elevated to the presidency. The success of his administration is attested by the spontaneous and earnest expressions of regret when, in 1876, he desired to resign his high office. At the meeting prior to the annual election, to use his own words, "What was read as a valedictory was listened to with great attention, after which a call to proceed to the business of the meeting was made. Instead of responding to this call, one after another of those whom the writer most respected addressed him in such terms of affectionate remonstrance against his resignation, as to induce him not only to withdraw it, but to feel that henceforth what had been regarded as a burden would be a joy, that the performance of the duties of his office would be sweetened as never before by the recognition that the respect and regard which he felt towards all the members were fully reciprocated by them." In 1880, on the completion of the fiftieth year of the society, and his tenth year as president, he declined re-election. But he performed no greater service to the Society or science than is represented by the admirable history of the Society's first half-century contributed in this year to its memorial volume. We search in vain, however, through this painstaking record, for any adequate account of his own labors. Nevertheless, although belonging to a later generation, I have had abundant opportunity to learn with what rare zeal and fidelity he served the Society; and I feel justified in stating that its extensive and efficient collections of minerals, rocks, and fossils were in a large measure created by him. It was throughout evidently a labor of love on his part; and that fact alone can explain how he was able to find in these busiest years of his life the great amount of time which this work must have required. Nor did his devotion to these departments cease with his accession to the presidency. It was my privilege, during the greater part of the decade when he was at the head of the Society's affairs, to work with him or under his direction in the care of these collections; and I can, therefore, speak from intimate personal knowledge of his methods. What most strongly impressed me were his affectionate regard for the specimens, and his absolute conscientiousness in every detail of the work. I often recall with much profit his painstaking investigations of individual specimens. He spared no pains to remove the last modicum of doubt as to the authenticity of species, variety, locality, composition, or formation, nor hesitated to use the query mark when the desired result could not be attained. Working in this methodical manner, progress could not be rapid when measured by hours. But what was done was well done; and he came

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THOMAS TRACY BOUVÉ.

THOMAS TRACY BOUVÉ, Resident Fellow of the Academy, was born on Prince Street, in Boston, January 14, 1815, and died in the city of his birth, June 3, 1896. He was of Huguenot descent. His parents were Ephraim Osborn and Lydia (Tracy) Bouvé, and his paternal grandfather was Jonathan Bouvé, a soldier of the Revolution. In 1839 he married Emily G. Lincoln; and his wife and five children survive him.

Very early in life he attended a private school; at the age of seven years he entered the Eliot public school, received the Franklin medal when twelve years of age, and then entered the English High School. It being necessary for him to do something for self-support, he left the school and entered a dry goods store. At fifteen he entered the service of an iron manufacturing company, where he became bookkeeper and chief accountant; later, he entered the office of the Hamilton, Appleton, and Lowell Manufacturing Companies to take charge of the books of these respective companies, and he also kept the books of the Great Falls Manufacturing Company. When about twenty-six years of age, Mr. Bouvé became a partner in a commission iron house, remaining in the business thirty years; and in 1870 he became treasurer of the Glendon Iron Company, retaining this office until his death.

Although his life was thus burdened to the end with the cares and responsibilities of a successful business career, they could not fetter his mind or stifle his interest in more distinctly intellectual pursuits. After leaving school he devoted much time to the study of chemistry, French, and Latin, and received the degree of A. M. from Harvard University in 1850. But the great central fact of Mr. Bouvé's life was his deep and abiding love of nature. This was manifested at a very early age, and throughout his long and busy life he was an ardent and steadfast student of natural history. His lifelong friend and associate, Dr. James C. White, justly describes him as a fine example of the amateur naturalist, and what this class has done for the advancement of science in this country.

Mr. Bouvé was only fifteen years old when the Boston Society of Natural History was founded. Four years later he became a member of the Society; and his labors in its behalf extended over more than threescore years, the period of his membership being the longest in its history. In fact, it was in connection with the Boston Society of Natural History, and especially in the building up of its collections, that his interest in natural history was chiefly manifested.

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vard, dear to him, were devoting themselves. He cherished with peculiar tenderness the memory of those who fell in the war. He was the main promoter of the two precious volumes of Harvard Memorial Biographies; and on the walls of his study, always before his eyes, close by the portraits of his old masters in learning, the brothers Jacob and Wilhelm Grimm, were those of his young heroic friends, the brothers Charles and James Lowell.

His fidelity in the discharge of the exacting duties of his professorship was complete. For far too many years far too much of his time was occupied in the correction of students' themes. He never shirked this wearisome drudgery. No teacher was ever more exacting of himself in the discharge of his regular duties. In the later years of his life, when he suffered much from gout and rheumatism, he did not allow pain or depression of spirits to interfere with the regular discharge of his task as instructor.

Even the dullest and most careless undergraduate could hardly fail to be quickened and improved by such teaching as Mr. Child's. Here was a master of most accurate and extensive learning, a scholar of unwearied diligence and exact method, with the faculties and sympathies which enabled him to impart his learning to his pupils, and to inspire in the more capable among them something of his own enthusiasm for the best in literature and life.

It is impossible not to regret that Mr. Child should not have done more independent literary work. The several introductions to the Ballads in his great collection, excellent as they are in their kind, very seldom afford him free space for the display of his own genius; but they abound in touches which light up the page with gleams of fancy or of humor, and more rarely with a flash of poetic imagination that reveals the restraint which the editor had imposed upon himself. His style when at freedom was of the best, — for it was the simple expression of the man himself.

Original, quaint, humorous, sweet, sympathetic, tender-hearted, faithful, — these are the terms which first come to mind in describing him; the traits that these terms imply included all his intelligence, gave character to his work, and made his learning the least part of him.

Those who knew him best think of him mainly as one who had the gift of love. He was a lover of nature, of poetry, of roses, of all that was fair and sweet and good; above all he was a lover of his fellow men. When he died the world lost much more than one of its great scholars.

C. E. Norton.

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June. He took no vacation, but busied himself in his study, and found pleasure in his garden of roses. In August he became seriously ill, and on the 11th of September he died.

Mr. Child's fame as a scholar is secure. His work is so done that it can never be superseded. But to those who had the happiness of intimacy with him, his learning and all that he accomplished seem but as secondary and accessory to the essential qualities of his character and his manner of life. The sedentary nature of his occupations, and their narrow material confines within the limits of a University helped to preserve the strongly marked and altogether delightful originality of his nature from the pressure and attrition of the world, which speedily wear down the marks of distinctive individuality and shape the mass of men into a general dull uniformity. He had a most sympathetic and tender heart, so easily touched that its impulses might sometimes have overcome the restraint of good judgment, had they not been encountered by his keen, kindly, and lively humor, which, while it generally saved him from sentimental extravagances, yet became often the inciter and ally of his liberal sympathies. His charity might be abused, but his pity included even the most open of impostors, and, taking a humorous enjoyment in the success of deceits practiced upon himself, he chose rather to aid the undeserving than to let a single deserving needy man go by unhelped.

The same liberality of disposition was manifest in his relations to all whom he could assist in literary or scholarly work. He made a friend of every young scholar who sought from him advice or direction, and gave his time willingly to serve interests not his own. He could be merciless with pretenders, but he was marvellously patient with unpretending and innocent incompetence.

With the highest sense of the duties and the privileges of his calling, he did not regard them as exempting him from the discharge of the common duties of a citizen. He did not bury himself in his books, and he had nothing of the indifference of a recluse to the affairs of the community in which he lived. His feelings were strong and his judgment was sound in regard to the matters affecting public interests. His opinions carried weight, for they were based on principles and maintained with clear intelligence and ready wit. If roused by argument, no one was his match in the flash of wit and the play of humor. He took the part of a good citizen in local politics; he was for many years an active member and officer in local charities, and he served his term as a member of the School Committee. At the time of the civil war he threw himself with ardor into the service of the cause to which so many of the youth of Har-

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exhibited by them, the wide diffusion among the nations of Europe of the legends which many of them embodied, opened a field of investigation of enormous extent, requiring acquaintance alike with many languages and many literatures. The task was one with which only a scholar possessed of exceptional acquisitions could hope to accomplish satisfactorily, and from which even the most industrious might have shrunk. It had hardly a parallel in the variety of learning which it exacted for its due performance, but this was not all; it demanded in no less measure fine critical acumen and poetic appreciation, — the gifts of taste and culture as well as of scholarship. Mr. Child possessed them all.

"It was my wish," he said, in the Advertisement prefixed to the first part, "not to begin to print The English and Scottish Popular Ballads, until this unrestricted title should be justified by my having at command every valuable copy of every known ballad. . . . What is still lacking is believed to bear no great proportion to what is in hand. . . . Meanwhile the uncertainties of the world forbid a longer delay to publish so much as has been got together."

From year to year the parts followed in rapid succession, — rapid in view of the character of the work, — and in the Advertisement to Part IX., which appeared in the spring of 1894, Mr. Child had the satisfaction of saying that, to the extent of his knowledge of sources the collection was complete, with the exception of a single ballad, "which is probably a variety of one or another here given in several forms." Such had been the extraordinary success of his research, in which he had been aided by many English and foreign scholars glad to assist in the perfecting of a work which was of interest to them in itself, and which roused their admiration by the manner in which it was executed.

The body of the work was complete; but one more part was needed, to contain a general Introduction, a Glossary, and Indexes. In spite of failing health Mr. Child set himself resolutely to the drudgery involved in this task. To the last month of his life he labored steadily, but with a sense of weariness to which he had been unused. With the exception of the Introduction the task was mainly accomplished, and the work was left in such condition that it could be taken up and carried through by the most competent hands next to Mr. Child's own, those of his disciple, assistant, and friend, Professor Kittredge.

The year 1895–96 completed the fiftieth year of Mr. Child's service in the University. It was a matter of satisfaction to him that during its course he had been able, in spite of physical infirmity, to meet his classes without the omission of a single lecture. The College year ended in

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work. But a more important piece of work, one of original investigation and displaying "wonderful industry, acuteness, and accuracy," * was the treatise issued in the Memoirs of our Academy in 1862 under the modest title of "Observations on the Language of Chaucer," † which was followed in 1868 by a Supplement, entitled "Observations on the Language of Gower's Confessio Amantis." ‡ "It is difficult at the present day," says Professor Kittredge, "to imagine the state of Chaucer philology at the moment when this paper appeared. Scarcely anything, we may say, was known of Chaucer's grammar and metre in a sure and scientific way. Indeed, the difficulties to be solved had not even been clearly formulated. . . . Mr. Child not only defined the problems, but provided for most of them a solution which the researches of younger scholars have only served to substantiate. He also gave a perfect model of the method proper to such investigations, — a method simple, laborious, and exact." §

For many years after this Mr. Child published little, but with steady purpose devoted such leisure as his incessant professional task allowed to the extension of the vast stores of his learning, and to the accumulation of the material for the main work of his life, a complete critical edition of "The English and Scottish Ballads." At length in 1882 appeared the first part of his work. The character of the undertaking was set forth in a prospectus. The popular Ballads existing in the English language had never been collected into one body; a large portion of the remains of the ballads was unprinted; the text of much that was in print was vitiated by editorial changes; it was now proposed to publish all in their entirety and their purity; to include every independent version of every ballad, and to record all important variations of different copies, both printed and manuscript; each ballad was to have a proper Preface, and in the case of those ballads which the English have in common with other nations an account was to be given of related traditions. The work was to be completed by a general introduction, a glossary, and indexes. The vast scale of this matured design became obvious on the publication of the first part. The large range of the themes of the ballads, the immense variety of local, historical, and romantic tradition

* These are the terms used by Mr. A. J. Ellis, the learned author of the History of English Pronunciation.

† Memoirs of the American Academy, New Series, Vol. VIII. pp. 445–502.

‡ Ibid., Vol. IX. pp. 265–315.

§ From the admirable appreciation of Professor Child's character and works in the Atlantic Monthly for December, 1896.

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of the true objects of life, and of the motives by which the educated man, whatever might be his chosen career, should be inspired, together with the serious and eloquent earnestness with which it was delivered, gave to his discourse peculiar impressiveness and effect.*

Immediately upon his graduation he was appointed Tutor in the College, with duties of instruction in English. To the study of the English language and literature he was led by taste, and his knowledge was already considerable in this wide field, to the cultivation of which the remainder of his life was to be in great part devoted, and in which he was to become an acknowledged master. In 1848 he published his first work, an edition in one volume of "Four Old Plays," all of the sixteenth century, and of interest to the student of the development of the English drama as exhibiting its conditions immediately before its splendid manifestation in the works of the Elizabethan playwrights. Nothing of the kind had been done previously in America. The volume appealed to but a small class of readers, but, with those who were competent to judge of it, it established the reputation of its editor as a scholar of more than usual competence of learning and sobriety of judgment.

In 1851, on the resignation of Professor Channing as Boylston Professor of Rhetoric, Child was appointed his successor with leave of absence for study in Europe, before assuming the duties of the position. The opportunities which Europe then afforded to the young American scholar were diligently made use of. He obtained the degree of Doctor of Philosophy at Göttingen in 1854, and in the autumn of the same year he returned to his work at Harvard. A great part of his time was employed in the teaching of English composition, and the drudgery of correcting students' exercises, but he had an indefatigable industry and a steady ardor of learning, and he found time to carry on his own special studies. He undertook the general superintendence of a series of the works of the chief British Poets, and himself prepared for it the edition of Spencer (1855) in five volumes, which for the use of the general reader still remains the best. For the same series he compiled a Collection of Ballads in eight volumes, published in 1857–58, which in extent of range, in judgment in selection, and in thoroughness of literary and historical illustration, was far superior to any preceding similar

* An eminent living graduate of Harvard, who was present on the occasion, having come to Cambridge to take his entrance examination, has said that he received from that oration his first vivid sense of the dignity of intellectual pursuits, and his first strong impulse to devote himself to them.

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his classes was so unmingled with pretension or conceit, that it was admitted without question or envy. Mr. Dixwell became strongly attached to him, and, in view of the great promise of his talents and his character, secured the means for his support in college, which he entered in the autumn of 1842.* Harvard was then still a comparatively small institution, with no claims to the title of University; but she had her traditions of good learning as an inspiration for the studious youth, and still better she had teachers who were examples of devotion to intellectual pursuits, and who cared for those ends the attainment of which makes life worth living. Josiah Quincy was approaching the close of his term of service as President of the College, and stood before the eyes of the students as the type of a great public servant, embodying the spirit of patriotism, of integrity, and of fidelity in the discharge of whatever duty he might be called to perform. Among the Professors were Walker, Felton, Peirce, Channing, Beck, and Longfellow, men of utmost variety of temperament, but each an instructor who secured the respect no less than the gratitude of his pupils.

The Class to which Child belonged numbered hardly over sixty. The prescribed course of study which was then the rule brought all the members of the Class together in recitations and lectures, and every man soon knew the relative standing of each of his fellows. Child at once took the lead and kept it. His excellence was not confined to any one special branch of study, he was equally superior in all. He was the best in the classics, he was Peirce's favorite in mathematics, he wrote better English than any of his classmates. His intellectual interests were wider than theirs, he was a great reader and his tastes in reading were mature. He read for amusement as well as for learning, but he did not waste his time or dissipate his mental energies over worthless or pernicious books. He made good use of the social no less than of the intellectual opportunities which college life affords, and became as great a favorite with his classmates as he had been with his schoolfellows.

The close of his college course was marked by the exceptional distinction of his being chosen by his classmates as their Orator, and by his having the first part at Commencement as the highest scholar in the Class. His Class Oration was remarkable for its maturity of thought and of style. Its manliness of spirit, its simple directness of presentation

* The pecuniary debt thus incurred was afterwards paid with interest. But though only thus could Mr. Child's spirit of independence be satisfied, he cherished through life the most grateful affection for the friend who had thus served him.

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REPORT OF THE COUNCIL.

SINCE the Annual Meeting of May 13, 1896, the Academy has lost by death seventeen members: —four Resident Fellows, Thomas Tracy Bouvé, Francis James Child, Benjamin Apthorp Gould, and Francis Amasa Walker; five Associate Fellows, George Brown Goode, Atticus Green Haygood, Matthew Carey Lea, Henry Newell Martin, and Hubert Anson Newton; and nine Foreign Honorary Members, Heinrich Ernst Beyrich, Ernst Curtius, Emil Heinrich Du-Bois Reymond, Hugo Glydén, Friedrich August Kekulé, Baron Ferdinand von Mueller, Jules Simon, James Joseph Sylvester, and Karl Weierstrass.

FRANCIS JAMES CHILD.

FRANCIS JAMES CHILD was born in Boston, on the 1st of February, 1825. His father was a sailmaker, one of that class of intelligent and independent mechanics which has had a large share in determining the character of our democratic community, as of old the same class had in Athens and in Florence. The boy was the youngest of five brothers and sisters. He was sent to the public schools. His unusual capacities were early displayed. He stood first in his classes, and was a favorite with his schoolfellows. At the English High School he won all the prizes, and having by chance attracted the attention of our venerable fellow citizen, Mr. Epes S. Dixwell, then the Master of the Latin School, his father was induced, at Mr. Dixwell's suggestion, to allow him to proceed to the Latin School, that he might continue his studies and be prepared for entrance to college. He speedily caught up with the boys who had already made progress in the study of Greek and Latin, and soon took the first place here, as he had done in the schools which he had previously attended. The sweetness of his disposition, the pleasant mingling in his nature of gay spirits and serious purpose, his high principles, his unaffected modesty won the affection of his teachers and of his comrades. His superiority in

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AMERICAN ACADEMY OF ARTS AND SCIENCES.

REPORT OF THE COUNCIL. — PRESENTED MAY 12, 1897.

BIOGRAPHICAL NOTICES.

FRANCIS JAMES CHILD	BY C. E. NORTON.
THOMAS TRACY BOUVÉ	W. O. CROSBY.
FRANCIS AMASA WALKER	CHARLES F. DUNBAR.
BENJAMIN APTHORP GOULD	SETH C. CHANDLER.

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Eight hundred and ninetieth Meeting.

April 14, 1897.

The Academy met at the house of John C. Ropes.

VICE-PRESIDENT George L. Goodale in the chair.

The chair announced the death of James Joseph Sylvester and Karl Weierstrass, Foreign Honorary Members in Class I, Section 1.

The following papers were read : —

The study of English at Harvard College. By Barrett Wendell.

Electricity and Ether. By Arthur G. Webster.

The following papers were presented by title :—

A Measure of Variability and the Relation of individual Variations to specific Differences. By Edwin Tenney Brewster. Presented by E. L. Mark.

Contributions from the Gray Herbarium of Harvard University. New Series, No. XI. — 1. Revision of the Mexican and Central American Species of *Houstonia*. 2. Key to the Mexican Species of *Liabum*. 3. Descriptions of new and little known Plants from Mexico. By J. M. Greenman. Presented by B. L. Robinson.

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Eight hundred and eighty-ninth Meeting.

March 10, 1897. — STATED MEETING.

VICE-PRESIDENT John Trowbridge in the chair.

The Corresponding Secretary read a letter from the Royal Academy of Sciences of Turin, announcing the death of Luigi Schiaparelli; also, one giving notice of the terms for competition for the eleventh Bressa prize.

The chair appointed the following committee to nominate officers for the ensuing year: —

Leonard P. Kinnicutt, of Class I., Henry P. Bowditch, of Class II., and Andrew M. Davis, of Class III.

The following gentlemen were elected Members of the Academy: —

Charles Henry Fernald, of Amherst, to be a Resident Fellow in Class II., Section 3 (Zoölogy and Physiology).

Ludwig Boltzmann, of Vienna, to be a Foreign Honorary Member in Class I., Section 2 (Physics), in place of the late Friedrich August Kekulé.

Wilhelm Pfeffer, of Leipsic, to be a Foreign Honorary Member in Class II., Section 2 (Botany), in place of the late Baron Ferdinand von Mueller.

Wilhelm Dörpfeld, of Athens, to be a Foreign Honorary Member in Class III., Section 2 (Philology and Archæology), in place of the late Ernst Curtius.

The following papers were read: —

International Bimetallism. By George S. Boutwell.

On the Minimal Nutrients of Bacteria in Water. By W. T. Sedgwick and D. D. Jackson.

An Investigation of some of the Bacteriological Aspects of the Art of Tanning. By S. C. Prescott. (By invitation.)

The Energy Conditions necessary to produce the Röntgen Rays. By John Trowbridge. (By title.)

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Eight hundred and eighty-seventh Meeting.

January 13, 1897. — STATED MEETING.

The PRESIDENT in the chair.

The chair announced the death of Francis Amasa Walker, Resident Fellow; Henry Newell Martin, Associate Fellow; and Emil Heinrich Du-Bois Reymond, Foreign Honorary Member.

The Corresponding Secretary read letters from the Secretary of the Pasteur Committee in Washington, announcing the opening of subscriptions in America, and inviting the Academy to participate, and from the Observatory of San Salvador announcing the death of its director, Don Alberto Sanchez.

The vacancies occasioned by the death of Benjamin A. Gould were filled by the election of

JOHN TROWBRIDGE, *Vice President for Class I.*

THEODORE W. RICHARDS, *Member of the Rumford Committee.*

On the recommendation of the C. M. Warren Committee it was

Voted, That the sum of two hundred dollars ($200) from the income of the C. M. Warren Fund be granted to H. O. Hofman, of Boston, for the prosecution of a research on the formation temperatures of slags in the smelting of ores of lead and copper or other metals.

S. H. Scudder read by title a paper on The Genera of North American Melanopli.

A. Lawrence Rotch read a paper on Obtaining Meteorological Records in the Upper Air by Means of Kites and Balloons.

Eight hundred and eighty eighth Meeting.

February 10, 1897.

The Academy met at the house of A. Lawrence Rotch.

The PRESIDENT in the chair.

The following papers were read: —

The Hebrew and Muhammedan Calendars. By William E. Story.

Forts Henry and Donelson. By John C. Ropes.

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The chair announced the death of Benjamin Apthorp Gould, Vice-President of the Academy for Class I., and of Hugo Gyldén, Foreign Honorary Member.

The Corresponding Secretary read a letter from James C. Carter, acknowledging his election as Associate Fellow.

On the motion of Charles L. Jackson it was

Voted, That the money received from the sales of publications in any year be appropriated for the publications of that year.

Voted, That the sum of four hundred and sixty-one dollars be added to the appropriation for publications this year, as this is the amount of the subscription raised to be used for publications, but not yet appropriated for this purpose.

On the motion of S. C. Chandler it was

Voted, To grant the use of the Hall of the Academy to the Colonial Society of Massachusetts on the third Wednesday of each of the five months December to April, in the same way as during the past year.

In view of the expected absence of the Recording Secretary, the President appointed William R. Livermore Recording Secretary *pro tempore*.

John E. Wolff exhibited a crystal of tourmaline from Paris, Maine, which had just been given to the Harvard Mineralogical Museum and is remarkable for its size and color. It is seven inches long, with a diameter varying from two to three inches, and weighs twelve hundred and twelve grammes, or two pounds eleven ounces avoirdupois. The color is a clear, transparent green, except at one end, where the crystal is tipped with red (rubellite) for half an inch. This is said to be the largest crystal of gem quality ever taken out from that famous locality.

William R. Livermore read a paper entitled, The Growth of the Roman Dominions in Europe from 650 B. C. to 200 A. D., illustrated by one hundred Sketches for an Atlas of Historical Geography.

The President described his recent explorations of the Florida elevated reefs, in connection with those of L. S. Griswold of Southern Florida.

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On the Butanes and Octanes in American Petroleum. By Charles F. Mabery and Edward J. Hudson.

On the Sulphur Compounds and Unsaturated Hydrocarbons in Canadian Petroleum. By Charles F. Mabery and William O. Quayle.

On the Composition of a South American Petroleum. By Charles F. Mabery and Arthur S. Kittelberger.

On the Specific Refractive Power of Petroleum Hydrocarbons, and some of their Derivatives. By Charles F. Mabery and Edward J. Hudson.

The Viscosity of Mercury Vapor. By A. A. Noyes and H. M. Goodwin.

Contributions from the Zoölogical Laboratory of the Museum of Comparative Zoölogy at Harvard College. E. L. Mark, Director. No. 73. — Studies in Morphogenesis. 6. A Contribution to the Quantitative Study of Correlated Variation and the Comparative Variability of the Sexes. By C. B. Davenport and C. Bullard.

Voted, To meet on adjournment on the second Wednesday in November.

Eight hundred and eighty-fifth Meeting.

November 11, 1896. — ADJOURNED STATED MEETING.

VICE-PRESIDENT George L. Goodale in the chair.

As a quorum for business was not present it was

Voted, To meet on adjournment on the second Wednesday in December.

Eight hundred and eighty-sixth Meeting.

December 9, 1896. — ADJOURNED STATED MEETING.

The Academy met at the house of the President in Cambridge.

The PRESIDENT in the chair.

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Goode and Hubert Anson Newton, Associate Fellows; and Heinrich Ernst Beyrich, Ernst Curtius, Friedrich August Kekulé, Baron Ferdinand von Mueller, and Jules Simon, Foreign Honorary Members.

In the absence of the Corresponding Secretary, Charles Loring Jackson was requested to act in his place, and read the following letters: from Karl Weinhold, Alexandre Kovalevsky, M. Foster, and B. L. Gildersleeve, acknowledging their election into the Academy; from a committee of the Society of Colonial Wars in the District of Columbia, proposing a joint memorial meeting in memory of George Brown Goode; from the International Geological Congress, enclosing the programme for its seventh session; from the Northwest Mining Association, suggesting the creation of a Department of Mines in the United States Government as a cabinet office; from the widow of Heinrich Ernst Beyrich, announcing the death of her husband; from the Academy "Gioenia" of Natural Sciences at Catania, announcing the death of its President, Giuseppe Zurria; from General-Major Rykatchew, reporting his appointment as Director of the Central Physical Observatory at St. Petersburg in place of Heinrich Wild, resigned; and from the committee of the British Association for the Advancement of Science on Zoölogical Bibliography and Publication, asking for the cooperation of learned societies in the method of publishing scientific papers.

James Coolidge Carter, of New York, was elected an Associate Fellow in Class III., Section 1, in place of the late Atticus Green Haygood.

Alpheus Hyatt read a paper entitled, Cycle in the Life of the Individual (Ontogeny) and in the Evolution of its own Group (Phylogeny).

The following papers were presented by title: —

The Constituents of Pennsylvania, Ohio, and Canadian Petroleum between 150° and 220°. By Charles F. Mabery.

Refractive Power of the Hydrocarbons and Chlorine Derivatives described in the Preceding Paper. By Charles F. Mabery and Edward J. Hudson.

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Mr. President and Gentlemen of the Academy, — I accept the medals for Mr. Edison, and at his request I wish to express his deep sense of the great honor the Academy has conferred upon him. His work in the field of electric lighting has been the subject of prolonged litigation, and at times he has had doubts in reading the opinions of learned experts whether this work has been original or whether he has really contributed anything to the world's progress. The recognition of his labors by the American Academy of Arts and Sciences, regarded by Count Rumford in his gifts as the coequal of the Royal Society of London, is therefore especially grateful to him. Acting as his proxy, I thank the members of the Academy for the distinction which they have by their votes conferred upon him.

The following papers were presented by title: —

A Revision of the Atomic Weight of Magnesium. By Theodore William Richards and H. G. Parker.

A Revision of the Atomic Weight of Strontium. Second Paper: The Analysis of Strontic Chloride. By T. W. Richards and H. G. Parker.

Contributions from the Gray Herbarium of Harvard University. New Series, No. 10: — 1. Revision of the Genus *Tridax*. 2. Synopsis of the Mexican and Central American Species of the Genus *Mikania*. 3. Revision of the Genus *Zinnia*. 4. Revision of the Mexican and Central American Species of the Genus *Calea*. 5. A Provisional Key to the Species of *Porophyllum* ranging north of the Isthmus of Panama. 6. Descriptions of new and little known Phanerogams, chiefly from Oaxaca. By B. L. Robinson and J. M. Greenman.

On the group of real Linear Transformations whose Invariant is a real Quadratic Form. By Henry Taber.

David W. Cheever read an obituary notice of Richard M. Hodges.

Eight hundred and eighty-fourth Meeting.

October 14, 1896. — STATED MEETING.

The PRESIDENT in the chair.

The following deaths were announced: Thomas Tracy Bouvé and Francis James Child, Resident Fellows; George Brown

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"The Committee felt that they could not decide upon Mr. Edison's claims for priority in any particular invention in this new industry. Indeed, courts of law after prolonged litigation have found it difficult to decide how far Mr. Edison was in advance of contemporary workers. The task given to the Rumford Committee to decide who is the most worthy of the Rumford Medal, especially in the field of the application of electricity for the production of light and heat, is not an easy one. The number of investigators is now so large that it is no longer possible in general for one man to claim to be the first to apply electricity to a new field. The successful application is the result of many minds working on the same problem. Although the Committee did not feel justified in expressing the opinion that Mr. Edison invented the incandescent carbon filament lamp, or that he was the first to arrange such lamp in multiple on the circuit, thus producing what is popularly termed a subdivision of the electric light, or that the Edison dynamo had greater merits than the machine of Gramme and Siemens and others; still they are convinced that Mr. Edison gave a great impulse to the new industry, and that he was the first to successfully install a central electric lighting plant with the multitude of practical devices which are necessary. They believe that this impulse was due to his indefatigable application, to his remarkable instinct in whatever relates to the practical application of electric circuits, and to his inventive genius. They therefore have unanimously recommended to the Academy to bestow the Rumford Medals upon him, feeling that the work of Mr. Edison would especially appeal to the great founder of the medals, Count Rumford, if he were living."

The Academy has accepted the report of the Rumford Committee, and has voted to confer the gold and the silver medal upon Mr. Edison. The recipient finds it impossible to be present at this meeting of the Academy, and has requested Professor Trowbridge to act as his proxy, and to receive the medals for him.

In the name of the Academy I beg you, Professor Trowbridge, to accept the charge of conveying these medals to Mr. Edison's hands. It would be most ungracious for us who are assembled in this room, which is flooded by this steady and brilliant electric light, to withhold our personal thanks for what Mr. Edison's investigations and practical activities have done for us all. And, hence, I may venture to say that our thanks and all good wishes are to be conveyed with the Rumford Medals.

Professor Trowbridge replied as follows: —

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The chair appointed the following Standing Committees: —

Committee of Publication.

SAMUEL H. SCUDDER, SETH C. CHANDLER,
CRAWFORD H. TOY.

Committee on the Library.

AMOS E. DOLBEAR, G. STANLEY HALL,
SAMUEL HENSHAW.

Auditing Committee.

HENRY G. DENNY, JOHN C. ROPES.

In accordance with a vote adopted at the meeting of the 8th of April, the Rumford Premium, awarded at the last annual meeting to Thomas Alva Edison, was presented, John Trowbridge acting as Mr. Edison's proxy.

Vice-President Goodale, in presenting the medals, made the following remarks: —

It would be highly presumptuous for one whose knowledge of physics is of the most elementary character to occupy the time of the Academy by any statement of his own in conveying these medals. Happily such a course is unnecessary. The Chairman of the Rumford Committee has placed at our command a brief statement which makes clear the ground of the award.

"The Rumford Committee voted, June 22, 1893, that it is desirable to award the Rumford Medal to Thomas Alva Edison, in recognition of his investigation in the field of electric lighting, and they confirmed this vote on October 9, 1893, in the following words: 'Voted for the second time to recommend to the Academy that the Rumford Medal be awarded to Thomas Alva Edison for his investigations in electric lighting.'

"The Committee reached the conclusion expressed by these votes after long deliberation and after careful sifting of all the evidence which was at their disposal in regard to Mr. Edison's claim for priority in the construction of the incandescent lamp, the conception of the central lighting station, together with the multitude of devices, such as the three-wire circuit, the disposition of the electric current feeders, and the necessary methods for maintaining the electric potential constant.

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ALEXANDER AGASSIZ, *President.*
BENJAMIN A. GOULD, *Vice-President for Class I.*
GEORGE L. GOODALE, *Vice-President for Class II.*
AUGUSTUS LOWELL, *Vice-President for Class III.*
SAMUEL H. SCUDDER, *Corresponding Secretary.*
WILLIAM WATSON, *Recording Secretary.*
ELIOT C. CLARKE, *Treasurer.*
HENRY W. HAYNES, *Librarian.*

Councillors.

HENRY MITCHELL,
LEONARD P. KINNICUTT,
EDWIN H. HALL, } of Class I.

HENRY P. BOWDITCH,
WILLIAM M. DAVIS,
ROLAND THAXTER, } of Class II.

ANDREW M. DAVIS,
HORACE E. SCUDDER,
JOHN E. HUDSON, } of Class III.

Member of Committee of Finance.

AUGUSTUS LOWELL.

Rumford Committee.

JOHN TROWBRIDGE, CHARLES R. CROSS,
ERASMUS D. LEAVITT, AMOS E. DOLBEAR,
EDWARD C. PICKERING, BENJAMIN A. GOULD,
ARTHUR G. WEBSTER.

C. M. Warren Committee.

FRANCIS H. STORER, HENRY B. HILL,
CHARLES L. JACKSON, LEONARD P. KINNICUTT,
SAMUEL CABOT, ARTHUR M. COMEY,
ROBERT H. RICHARDS.

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This question has been carefully considered by the committee. After full debate, it was voted that "In the opinion of the Committee no general appropriation for the purchase of books can properly be made from the C. M. Warren Fund."

F. H. STORER, *Chairman.*

On the recommendation of the Committee of Finance it was

Voted, To make the following appropriations from the income of the General Fund for the ensuing year: —

For general expenses	$1,950.00
For the Library	1,350.00
For publications	2,300.00

Voted, That the assessment for the ensuing year be five dollars ($5.00).

In accordance with the recommendation of the Rumford Committee it was

Voted, That one thousand dollars ($1,000) from the income of the Rumford Fund be placed at the disposal of the Rumford Committee, to be expended in aid of investigations in light and heat, payments to be made on the order of the Chairman of the Committee.

In accordance with the recommendation of the C. M. Warren Committee, it was

Voted, To appropriate six hundred dollars ($600) from the income of the C. M. Warren Fund to C. F. Mabery, of Cleveland, Ohio, in aid of his researches on the chemistry of petroleum.

Upon motion it was

Voted, That the thanks of the Academy be tendered to Charles Loring Jackson for his faithful and efficient services as Corresponding Secretary.

The annual election resulted in the choice of the following officers and committees: —

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one for the medal at this time. The Rumford Committee has been presented by Professor Marcou with copies of forty-eight letters written by Count Rumford to Professor Pictet of Geneva. The committee voted to recommend to the Academy that it authorize the printing at the expense of the Rumford Fund of the following four papers, and that a sum of $25 be appropriated for illustration of these papers.

The titles of these papers are as follows: —

1. Thermo-electric Interpolation Formulæ, by S. W. Holman.
2. The Melting Points of Aluminum, Silver, Gold, Copper, and Platinum, by S. W. Holman with R. R. Lawrence and L. Barr.
3. Pyrometry: Calibration of the Le Chatelier Thermoelectric Pyrometer, by S. W. Holman.
4. Calorimetry: Methods of Cooling Correction, by S. W. Holman.

The committee voted to authorize the publication in the American Journal of Science of a preliminary account of an investigation on the thermal conductivities of certain kinds of stone, by Prof. B. O. Peirce and Dr. R. W. Willson. Professor E. H. Hall's paper on the Thermal Conductivity of Mild Steel was presented to the Academy, January 8, 1896, and has been published by the aid of the Rumford Fund.

It is the desire of the Committee that the vote of the Academy at its last annual meeting to appropriate from the Rumford Fund the sum of one thousand dollars, to be expended at the discretion of the committee in aid of investigations in light and heat, — payments from the sum to be made on the order of the Chairman of the Committee, — should be reaffirmed at the present meeting.

JOHN TROWBRIDGE,
Chairman Rumford Committee.

REPORT OF THE C. M. WARREN COMMITTEE.

I have to report that the recipients of the money granted by the Academy from the Cyrus M. Warren Fund have been doing good work.

This statement is borne out very emphatically by the publications of Professor Mabery, which are of a high order of excellence.

At the last annual meeting it was voted by the Academy "that the C. M. Warren Committee be requested to consider the propriety of appropriating $50 from the income of the C. M. Warren Fund for the purchase of books relating to chemical research."

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WARREN FUND.

Receipts.

Balance, May 1st, 1895	$374.89
Income	840.00
	$1,214.89

Expenditures.

Investigations	$600.00
Balance	614.89
	$1,214.89

BUILDING FUND.

Receipts.

Balance, May 1st, 1895	$843.68
Income	445.00
	$1,288.68

Expenditures.

Investment	$1,000.80
Balance	288.68
	$1,288.68

The Librarian presented his annual report, which showed that 3,096 books and pamphlets had been added to the Library during the year, 2,106 of which were obtained by gift and exchange, 748 by purchase with the appropriation from the General Fund, and 242 with the appropriation from the Rumford Fund. 345 volumes were bound at an expense of $383.55, of which $22.35 were charged to the Rumford Fund. The total expenditure for books, periodicals, and binding amounted to $1,297.95, of which $140.17 were charged to the Rumford Fund. 196 books were borrowed by thirty-five persons, of whom twenty-three were Fellows of the Academy.

The following reports were also presented: —

REPORT OF THE RUMFORD COMMITTEE.

The Rumford Committee has considered since the last annual meeting of the Academy all possible candidates for the Rumford Medal, but has been unable to reach a conclusion, and therefore does not recommend any

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General Fund.

Receipts.

Balance, May 1st, 1895			$2,675.24
Sale of bonds			15,233.75
			17,908.99
Assessments	$1,050.00		
Sale of publications	9.10	$1,059.10	
Income from investments		4,677.00	
Return of bank tax		51.51	
Gift of E. C. Clarke		100.00	
Gift of F. H. Storer		5.00	5,892.61
			$23,801.60

Expenditures.

General expenses		$2,039.00	
Publishing expenses		1,939.14	
Library expenses		1,157.78	$5,135.92
Investments			16,550.00
Balance			2,115.68
			$23,801.60

Rumford Fund.

Receipts.

Balance May 1st, 1895			$5,863.70
Sale of bonds			3,550.00
Income		$1,952.00	
Return of bank tax		91.72	2,043.72
			$11,457.42

Expenditures.

Books and binding		$140.17	
Rent		10.00	
Investigations		1,000.00	
Publishing expenses		71.42	
Rumford Medal		327.50	1,549.09
Investments			8,000.00
Balance			1,908.33
			$11,457.42

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PROCEEDINGS.

Eight hundred and eighty-third Meeting.

May 13, 1896. — ANNUAL MEETING.

VICE-PRESIDENT George L. Goodale in the chair.

The chair announced the death of Atticus Green Haygood, Associate Fellow.

The Corresponding Secretary read the following letters: from Charles Lane Poor and T. R. Lounsbury, acknowledging their election as Associate Fellows; from the Librarian of the Boston Public Library, announcing the preparation of a list of serial publications now taken in the principal local libraries, and inviting correspondence from persons owning periodicals not to be found in public collections and willing to offer them for occasional consultation; from the College of New Jersey, inviting the Academy to send a delegate to the sesquicentennial celebration of the founding of the College; and from the Principal of the University of Glasgow and the Lord Provost of Glasgow, inviting the Academy to appoint a representative to attend the jubilee of Lord Kelvin on the 15th and 16th of June next. The chair appointed William Everett delegate to the celebration at Princeton.*

The Corresponding Secretary read the Report of the Council.

The Treasurer presented his annual report, of which the following is an abstract: —

* Mr. Everett being unable at the last moment to attend, his place was filled by the appointment of Horace E. Scudder, as substitute.

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Proceedings of the American Academy of Arts and Sciences.

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PROCEEDINGS OF THE ACADEMY, 1896-1897.

REPORT OF THE COUNCIL: BIOGRAPHICAL NOTICES.

Francis James Child. By C. E Norton.

Thomas Tracy Bouvé. By W. O. Crosby.

Francis Amasa Walker. By C. F. Dunbar.

Benjamin Apthorp Gould. By Seth C. Chandler.

LIST OF THE FELLOWS AND FOREIGN HONORARY MEMBERS.

STATUTES AND STANDING VOTES.

INDEX.

(Title Page and Table of Contents.)

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flowers numerous (about 60), including the achenes 2 cm. or more in length: achenes short, columnar, striate, puberulent, 3 mm. long in the flowering stage: pappus silvery white. — Collected by C. G. Pringle, on a wet barranca above Cuernavaca, altitude 2,000 m., 1 November, 1896, no. 6626. A very distinct species of *Cacalia*, the younger leaves much resembling the foliage of *Senecio reticulatus*, DC., and with the inflorescence of *C. platylepis*, Rob. & Seaton.

Cynara Cardunculus, L. This very showy plant, native of the Old World, appears not to have been hitherto recorded from Mexico. It was collected by Wislizenus, at Saltillo, Coahuila, no. 310, and by E. W. Nelson, at Celaya, Guanajuato, no. 3866.

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pubescent: pappus of about 8 broadly obovate scarious scales, 2 mm. long, nearly or quite as broad: achenes puberulent, 4 to 5 mm. long. — Collected by C. G. Pringle, on calcareous bluffs, near Tula, altitude 2,100 m., 6 August, 1896, no. 6407. Allied to *B. Schaffneri*, Wats., from which it is distinguished by its perennial base, large heads and flowers.

Tagetes triradiata. An annual erect branching glabrous herb, 4 to 5 dm. high: stems sulcate, striate, greenish purple: lower branches opposite, upper alternate, ascending: leaves imparipinnately divided to the narrowly winged midrib; divisions subopposite in 7 to 10 pairs, narrowly lanceolate, dentate with acute and often setigerous teeth, 10 to 16 mm. long, 3 to 6 mm. broad, much reduced near the base of the leaf: inflorescence paniculate, formed by the branches terminating in slender pedunculate heads: peduncles somewhat thickened above, 2 to 3 cm. long: heads cylindrical or somewhat spindle-shaped, 1 to 1½ cm. long, about 12-flowered; involucre greenish purple, obtusely 3–4-dentate, often split down the side to one third its entire length; rays three, bright yellow, including the achenes 14 mm. long, tube somewhat angular, puberulent on the angles, the expanded portion unequally 3-lobed, about twice as broad as long; disk-flowers polygonal, puberulent: pappus variable, usually of 6 unequal scales, 2, 3, 4, or even 5 of the scales hispidulous, long acuminate-aristate, the others short linear-oblong or spatulate, obtuse; achenes appressed-puberulent, about 7 mm. long. — Collected by C. G. Pringle, Pedigral (lava beds), Valley of Mexico, altitude 2,300 m., 12 October, 1896, no. 6592. In general habit closely resembling *T. fœtidissima*, DC., differing, however, in the number of the ray-flowers, the character of the same, and also in the character of the pappus.

Cacalia suffulta. Stems 2 to 3 m. high, terete, sulcate-striate, purple, glabrous, leafy throughout: lower leaves orbicular-ovate, cordate, 15 to 18 cm. long, 18 cm. or more broad, palmately nerved, 9–11-lobed, mucronate-denticulate, above glabrous, below hirsutish on the strongly reticulated veins; petioles 10 to 12 cm. long; upper cauline leaves considerably smaller, 5 to 8 cm. long, equally broad, puberulent on the veins above (becoming glabrous), hirsutish on the veins and nerves beneath, becoming gradually reduced above to the sessile foliar bracts of the subcorymbose inflorescence: outer clusters of the corymb on long naked striated purple peduncles: heads large, 2 to 2½ cm. high, about 2 cm. in diameter, subtended and rather closely enveloped by ovate-oblong obtuse sessile bracts: involucre about 2-seriate; scales oblong, obtuse, 10 to 14 mm. long, 3 to 4 mm. broad, greenish purple, glabrous, somewhat keeled on the back, much thickened at the base, apex often ciliated:

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Sclerocarpus Schiedeanus, Benth. & Hook., var. elongatus. A slender much branched herb, 1 to 1½ m. high: leaves lanceolate, 5 to 12 cm. long, 5 to 12 mm. broad: ray-flowers 5 to 8. — Collected by L. C. Ervendberg, at Wartenberg near Tantoyuca, Prov. Huasteca, 1858, nos. 98, 99, and by C. G. Pringle, in fields around Cuernavaca, altitude 1,600 m., 31 October, 1896, no. 6606. A variety readily recognized by its slender habit and long narrow leaves.

Verbesina oncophora, Rob. & Seaton? Specimens collected by C. G. Pringle, under bluffs of barranca above Cuernavaca, altitude 2,000 m., 1 November, 1896, no. 6600, agree in inflorescence and floral characters with this species, but differ conspicuously by having opposite or subopposite and more remotely denticulate leaves, also by the absence of any excrescences on the stems at the base of the leaves. Further material may show this plant to be worthy of specific rank, but for the present at least the writer prefers to regard it as a form of the above named species.

Verbesina stenophylla. Stems herbaceous, winged, erect from a ligneous base, about 1 m. in height, essentially glabrous below, hirtellous-puberulent above: leaves alternate, narrowly spatulate, 7 to 18 cm. long, 6 to 10 mm. broad, obtuse or acute at the apex, gradually narrowed below to a sessile decurrent base, entire or inconspicuously denticulate, somewhat roughened on the margins, glabrous above, below glabrous or in the earlier stages hirtellous, midrib prominent beneath, veins semitransparent, rather strongly reticulated; the upper leaves gradually reduced to linear-attenuate bracts: inflorescence in a single terminal head or disposed in a single cyme: heads few, about 12 mm. in diameter (including the rays 3 to 3½ cm. in diameter); involucral scales 2–3-seriate, linear, hirsute-pubescent; ligules yellowish white, about 10 in number, 10 to 12 mm. long; chaff oblong-linear, attenuate above to an acute apex, margin somewhat erose near the tip: achenes 6 mm. long, 4 mm. broad, strongly winged with subciliated margins, and scattered hirsute pubescence on either surface. — Collected by C. G. Pringle, on moist slopes above Cuernavaca, altitude 2,000 m., 18 September, 1896, no. 6503.

Bahia Pringlei. Perennial by slender rhizomes: stems branching from the base: branches ascending, 25 cm. or more high, hoary pubescent: leaves opposite or alternate, triternately compound, segments linear, obtuse, white hirsute-pubescent: heads 12 mm. high, nearly 2 cm. in diameter, usually on long slender peduncles: involucre about 3-seriate, hirsute; scales several, oblong-linear to subobovate, the inner ones with scarious margins: rays yellow, 6 to 7 mm. long, 2 mm. broad: disk-flowers numerous: corolla 5 mm. or more long, externally glandular-

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were secured which agree in every detail with the original plant collected by Berlandier in the Valley of Toluca, no. 1164. Our plant as well as the type shows the inflorescence and the scales of the involucre to be glandular-pubescent, a character not mentioned in De Candolle's description, Prodr. v. 115.

Eupatorium oreithales. Perennial from a horizontal root-stock: roots fibrous, rather stout: stems herbaceous, erect, purple, pubescent, 5 to 6 dm. high, leafy below, nearly naked above, frequently branching at the base: leaves opposite, broadly ovate, obtuse or rounded at the apex, subtruncate or short-cuneate at the base, crenate, hirtellous on the upper surface, puberulent on the veins beneath, becoming essentially glabrous, 2 to 5 cm. long, nearly or quite as broad: petioles pubescent, purple, 1 to 3 cm. long: heads few, disposed in loose terminal corymbs, about 10 mm. high, 50–60-flowered: involucral scales about 2-seriate, nearly equal, greenish purple, pubescent, linear-oblong, acute, ciliate, about 6 mm. long: corollas white, 4 to 5 mm. long, tubes slender below, about equalling the ampliated upper portion, the lobes pubescent on their outer surfaces: pappus about as long as the corolla-tube: achenes 3 mm. long, puberulent. — Collected by C. G. Pringle, on the Serrania de Ajusco, altitude 2,400 m., 28 September, 1896, no. 6563. Nearly related to *E. Saltivarii*, Schz. Bip., but readily distinguished by its broader more rotund and crenate leaves, and also by the nearly naked stem and longer petioles.

Eupatorium euonymifolium, Greene, Pittonia, iii. 31 = *E. Lemmoni*, Rob. Proc. Am. Acad. xxvii. 171.

Eupatorium kœlliæfolium, Greene, l. c. = *E. hyssopinum*, Gray, Proc. Am. Acad. xv. 28.

Gnaphalium linearifolium. Annual, becoming somewhat ligneous below, herbaceous above: stems terete, white-lanate, 2 to 4 mm. in diameter, simple or branched, 7 to 10 dm. high: leaves sessile, linear-attenuate, 1 (–3)-nerved, margin revolute, arachnoid-pubescent above, white-tomentose beneath, later becoming reflexed, 6 to 11 cm. long, about 2 mm. wide: inflorescence corymbose: heads sessile or nearly so, 6 mm. high; involucre about 4-seriate; scales stramineous, the outer ovate-acute, inner oblong-obtusish: flowers numerous, perfect flowers about ten: achenes terete, glabrous. — Collected by C. G. Pringle, on rocky hills near Guadalajara, 7 October, 1889, no. 2342 (distributed as *G. leptophyllum*, DC.); on the Sierra de San Felipe, at an altitude of 2,150 m., 17 November, 1894, no. 5685; and also in the latter locality by C. L. Smith, no. 592.

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broadly ovate or ovate-oblong, 9 to 11 mm. long, nearly as broad, convex on one surface, flat on the other with a short ridge near the base. — Collected by streams, Valley of Mexico, 10 October, 1896, no. 6226.

Stevia clinopodioides. An herbaceous perennial: roots fibrous, clustered at the base of the stem: stems simple or nearly so, about 30 cm. high, giving off at the base several slender horizontal subterranean root-stocks, closely pubescent above and purple: leaves opposite below, alternate above, spatulate, 2½ to 4 cm. long, 6 to 10 mm. broad, obtuse at the apex, gradually narrowed below to the subpetiolate base, callously serrate along the upper half, entire below, appressed-puberulent on the veins and on the upper surface near the margin, glandular-punctate: inflorescence a compact dense umbel terminating the stems: heads about 1 cm. long, 5-flowered; involucral scales linear-acuminate, often slightly unequal, appressed-puberulent on the outer surface, greenish purple, 6 to 7 mm. long: flowers considerably exceeding the involucre: corolla with a slender greenish tube below, ampliated above, the upper ampliated portion and the limb purple; pappus paleaceous, short, exaristate: achenes glabrous, 3 to 4 mm. long. — Collected by C. G. Pringle, on the Serrania de Ajusco, altitude 3,000 m., 22 October, 1896, no. 6594.

Stevia diffusa. Annual: roots fibrous: stems herbaceous, erect, terete, greenish purple, hirsutish pubescent with jointed hairs, interspersed above with a stipitate glandular pubescence: leaves (including the petiole) 3 to 7 cm. long, 1 to 4 cm. broad, opposite below, becoming alternate above, membranous, broadly ovate to ovate-lanceolate (the uppermost often acuminate), acute at the apex, contracted below into a narrowly winged and ciliated petiole, crenate-serrate, or the more reduced leaves with a subentire margin, essentially glabrous upon either surface, except on the veins, where they are sparingly hirtellous: heads widely separated on long slender glandular pedicels, the latter from 1 to 1½ cm. long; scales of the involucre 5, linear, acuminate, 6 mm. long, rather strongly 2-nerved, the outer surface appressed-puberulent, very rarely glandular: flowers one third longer than the involucre: corolla discolorous, tube purplish, puberulent, limb white: achenes puberulent, 3 mm. long: pappus paleaceous and 3-aristate. — Collected by C. G. Pringle, on lava beds near Cuernavaca, altitude 2,100 m., 3 November, 1896, no. 6608. Perhaps related to *S. micrantha*, Lag., but with longer corollas, shorter achenes, and a much more diffuse habit.

Stevia trachelioides, DC. It is interesting to note that Mr. Pringle has rediscovered this apparently rare species on the Serrania de Ajusco, altitude 3,000 m., 22 October, 1896, no. 6593, where specimens

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Crusea coccinea, DC., var. pubescens. Leaves ovate, acute, often short-acuminate, covered above with a scattered hirsute pubescence: corolla-tube, especially the lower slender portion, pubescent on the outer surface. — Collected by E. W. Nelson, on the west slope of Mt. Zempoaltepec, altitude 2,100 to 2,400 m., 5–13 July, 1894, no. 581; also on the northwestern slope of the same mountain, altitude 2,400 to 3,000 m., 10 July, 1894, no. 699. Differs from the species proper by the smaller leaves, the pubescence of the same, and by the pubescent corolla.

Crusea cruciata, Watson, var. villosior. Stem $\frac{2}{3}$ to 1 m. in height: leaves lanceolate, acuminate, 9 to 12 cm. long, 1 to 2 cm. broad; floral leaves villous-pubescent on the lower surface near the base: flowers white to purple. — Collected by Dr. E. Palmer, at Jalisco, 1886, no. 901, and by C. G. Pringle, near Cuernavaca, altitude 1,600 m., 17 September, 1896, nos. 6508, 7225. With habit, laciniate stipules, and essential characters of the type, but somewhat more robust, and with a rather striking villous pubescence on the broadened basilar portion of the floral leaves.

Crusea villosa, Watson, founded upon Pringle's no. 2448 from Jalisco, collected in 1890, also Pringle's no. 3257 from the same locality, collected in 1890 and distributed under the above name, may be referred to *Crusea Palmeri*, Gray. Notwithstanding the somewhat remote localities, both of Mr. Pringle's numbers are identical with Dr. Gray's type, collected by Dr. Edward Palmer in Southwestern Chihuahua.

Galium prætermissum. Perennial: the slender woody roots containing a red coloring matter: stems 3 to $4\frac{1}{2}$ dm. long, slender, weak, decumbent, purplish at the base, green above, glabrous or hispidulous on the angles: leaves in fours, sessile, linear-lanceolate, 8 to 14 mm. long, 1 to 3 mm. broad, acute, margin revolute (hispidulous on the older leaves), upper surface usually hispidulous, shining, glabrous beneath: flowers in subtrichotomous cymes: pedicels 3 to 10 mm. long, glabrous or minutely hispidulous: corolla rotate, yellow, 4(-3)-lobed; lobes ovate-oblong, obtuse or short-acuminate and obtusish: fruit long-hirsute with uncinate hairs. — Collected by C. G. Pringle, in pine woods, base of Sierra de Ajusco, altitude 2,460 m., 19 September, 1896, no. 6596. A species with the habit of *G. Mexicanum*, HBK., but with leaves in fours, not pungent-acuminate, and with much longer uncinate hairs on the fruit.

Viburnum elatum, Benth. Excellent flowering and fruiting specimens, apparently belonging to this species, have been secured by Mr. Pringle, and the following additional characters may be noted. Drupe ovoid, 12 to 14 mm. long, black, covered with a blue bloom; stone flat,

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slender, filiform, exceeding the corolla; stigma 2-parted: capsule subglobose, somewhat compressed laterally, 8 to 9 mm. long, equally broad, and 6 to 7 mm. thick. — Collected by C. G. Pringle, on a mountain side near Cuernavaca, State of Morelos, 18 November, 1895, no. 7062, and in the same locality in 1896, no. 6330. The above plant is in all probability the one described in HBK. Nov. Gen. & Spec. iii. 385, notwithstanding the little discrepancy as to the number of leaves in the whorl, and the quadrangular stem; the former character is a variable one, as shown by many species of the genus, and the angulation of the stem depends to a great extent upon the number of leaves in the whorl. It seems best, therefore, in view of the very meagre description of the above species, which was doubtless drawn from a very incomplete specimen, to regard the above cited numbers of Mr. Pringle as representing the *Bouvardia obovata*, HBK., and to amplify the characters of the same.

Hamelia nodosa, Mart. & Gal. Specimens agreeing in all essential characters with Walper's description of the above species (Walp. Rep. vi. 51) were collected by Rev. Lucius C. Smith at Ojitlan, Oaxaca, altitude 198 m., 21 August, 1895, no. 605. The plant differs, however, in having the fruit elliptic-oblong (6 to 9 mm. long, one half as broad) instead of globose.

Crusea calcicola. An herbaceous annual: stems erect, branching from the base, tetragonal, glabrous or hispidulous on the angles: leaves lanceolate or lance-oblong, 2 to 4½ cm. long, 6 to 13 cm. broad, acute, somewhat narrowed at the base, margin revolute, scabrous, midrib and veins prominent beneath, glabrous on either surface, slightly paler beneath; stipules puberulent, 3 to 4 mm. long bearing 3 to 7 setæ on either side: inflorescence in axillary or terminal pedunculate involucrate heads: peduncles above puberulent and often hispidulous on the angles: floral leaves (subtending the heads) 1 to 2 cm. long, ciliated at the broadened base: bracts strongly dilated at the base, short-acuminate, shorter than the floral leaves: flowers short-pedicellate, intermixed with numerous laciniate pales: calyx small, about 2 mm. long, 4-lobed; lobes slightly exceeding the tube, narrow, acute, long-ciliate: corolla tubular, narrowed below, somewhat ampliated above, 4-lobed, about 4 mm. long, white; lobes oblong, obtuse, usually bearing on the outer surface near the apex a few spreading hairs: stamens exserted: stigma overtopping the anthers. — Collected by C. G. Pringle, on dry calcareous hills, Las Sedas, Oaxaca, at an elevation of 1,800 m., 8 September, 1894, no. 4869. Distributed as *C. cruciata*, Wats., but differing from the latter species in the character of the stem, the stipules, and the bracts.

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several erect or spreading hairs on the outer surface near the tip: capsule 13 to 15 mm. long, glabrous. — Collected by C. G. Pringle, in a wet barranca above Cuernavaca, altitude 2,000 m., 21 September, 1896, no. 6506.

Justicia Clinopodium, Gray, in herb. Stems ascending or erect, usually branching, terete, 2 to 5 dm. high, lineolate pubescent, also covered with long spreading villous pubescence, often interspersed with glandular hairs: leaves short-petiolate, obtuse, entire, subcordate at the base, with a scattered villous pubescence on either surface, especially upon the veins beneath, 2 to 5 cm. long, 1 to $2\frac{3}{4}$ cm. broad: petioles short, 1 to 5 mm. in length; inflorescence in terminal pedunculate spikes becoming 8 cm. long; bracts and bractlets lanceolate, acute, 10 to 15 mm. long, covered on the outer surface and margin with long villous hairs intermixed with glandular hairs: calyx deeply 4-parted, the equal or subequal divisions linear-acute, about equalling the bracts, externally villous-pubescent: corolla glabrous, about 2 cm. long, purple, the upper lip shortly bifid, the lower deeply 3-lobed, segments subequal, oblong, rounded at the tip: stamens of the genus, but with the adnate portion pubescent: style smooth: capsule glabrous, about 13 mm. long; seeds compressed, more or less densely covered with shaggy armed trichomes. — Collected by Bourgeau, in the region of Orizaba, 25 August, 1866, no. 2901; also by Botteri in the same locality without number; and by Ghiesbreght, in Chiapas, 1864–70, nos. 80, 684.

Bouvardia obovata, HBK. A stout glabrous herb nearly a meter in height: stems simple, unbranched, angular, striate-sulcate; internodes 5 to 13 cm. in length: leaves verticillate, 5 to 8 in each whorl, narrowly obovate or oblanceolate, 4 to 12 cm. long, 1 to 3 cm. broad, usually obtusish and submucronate, sometimes acute, entire, revolute, subrepand and often hispidulous on the margins toward the apex, gradually narrowed below the middle to a subpetiolate base, rather dark green to olive green in color (in the dried state), slightly paler beneath; midrib and veins rather prominent, especially beneath; interpetiolar stipules subdeltoid, acute or short-acuminate, unequally serrulate or sublaciniate: inflorescence in a terminal close subtrichotomous cyme: peduncles 9 to 12 mm. long; the ultimate divisions pruinose-puberulent: calyx deeply 4(-5)-parted; divisions linear, about 3 mm. long, acute, often deeply colored, ciliate or subhispidulous on the margins: corolla tubular, 4(-5)-parted, $2\frac{1}{2}$ to 3 cm. long, deep red or crimson, minutely pruinose or puberulent on the outer surface, glabrous within; lobes ovate, acute, about 4 mm. long: anthers subsessile in the upper portion of the corolla-tube: style

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glabrous, resupinate, 5 to 6 mm. long, two thirds as broad; inner bracts linear-linceolate, nearly 5 mm. long, 1 mm. broad, margins scarious; bractlets linear-lanceolate, diaphanous, about 4 mm. long with a rudimentary flower in the axil: calyx deeply 5-parted; divisions lance-attenuate, ciliate: corolla bilabiate, 1½ to 2 cm. long, yellowish white striped with purple in the dried state, externally pubescent: stamens with filaments and anthers purple: capsule smooth, about 6 mm. long; seeds orbicular, flattened, muricate. — Collected by C. G. Pringle, on lava beds near Cuernavaca, altitude 1,500 m., 3 November, 1896, no. 6602; and by E. W. Nelson, near Tlalixtaquilla, Guerrero, 10 December, 1894, no. 2256.

Buceragenia, nov. gen. of *Acanthaceæ* (*Eujusticieæ*). Calyx 5-parted, segments linear, subequal. Corolla tubular; tube cylindrical, erect, not ampliated above; limb short, 2-labiate, posterior lip interior, incurved, deeply emarginate or shortly 2-lobed, anterior erect or scarcely spreading, 3-lobed, external. Stamens 2, anterior, inserted at the middle of the corolla-tube, included; anthers 1-celled, oblong, medio-dorsally affixed, obtuse. Staminodea 2. Disk annular, inconspicuous. Style slightly thickened above, stigma minutely and unequally 2-lobed; ovules 2 in each cell. Capsule oblong, narrowed below into a solid stipe; seeds 4, suborbicular, flattened, strongly muricate or roughened; retinacula slender; embryo normal. — Herbaceous perennials having their affinity with the genus *Habracanthus*, but differing by the shallowly bilabiate corolla, and the presence of staminodea. The generic name is taken from βοῦς, κέρας, and γίγνομαι, in reference to the Spanish name Cuernavaca, from which place it comes.

Buceragenia minutiflora. Stems erect, about 1 m. high, simple, nearly naked below, branched and leafy above, glabrous; branches slender, internodes 5 to 12 cm. in length: leaves ovate, usually acuminate with an obtusish apex, rather abruptly narrowed at the base and attenuated into a long narrowly winged petiole, entire or subrepand, ciliate, minutely lineolate on the upper surface with a few scattered hirsutish hairs, pubescent on the midrib and prominent veins beneath, dark green above, paler beneath: inflorescence in slender interrupted spikes or spikoid racemes terminating the stem and branches, puberulent and stipitate-glandular; spikes (4 to 13 cm. long) on slender peduncles; bracts ovate, acute, about 1 mm. long; bractlets minute: calyx 2 to 5 mm. long, 5-parted, persistent; divisions subequal, linear, acute, puberulent and stipitate-glandular: corolla minute, 2 to 3 mm. long, tubular, 5-nerved, slightly enlarged below; lobes oblong, rounded at the apex, covered with

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obtusish, entire or subrepand, ciliate, strigose-pubescent upon either surface, and hirsute upon the midrib and veins beneath, abruptly contracted below into a narrowly winged petiole; petioles 5 to 22 mm. long, hirsute-pubescent: inflorescence extra-axillary of 1 to 4 slender reflexed pubescent pedicels, becoming in fruit about 2 cm. long: calyx deeply 5-parted, densely covered with a long spreading hirsute pubescence; divisions linear-oblong, acute, 3 to 7 mm. long, more or less persistent: corolla about 1 cm. in diameter; lobes broadly ovate, short-pubescent at the acute apex, externally covered with a few long scattered jointed hairs: stamens 5, equal; anthers oblong: ovary glabrous, 2(-4)-celled: fruit smooth, about 8 mm. in diameter; seeds oblique-ovate, corrugated, 3 mm. long. — Collected by Lucius C. Smith, at Cuicatlan, 15 July, 1895, no. 403; E. W. Nelson, between Topana, Oaxaca, and Tonala, Chiapas, altitude 61 to 150 m., 1–3 August, 1895, no. 2876[a]; and by C. G. Pringle, on shaded hillsides near Cuernavaca, altitude 1,500 m., 26 July, 1896, no. 6400. A species apparently well characterized by the inflorescence, calyx, and pubescence. Most nearly related to the *Solanum nigrum* group.

Solanum Mitlense. Dun. Specimens agreeing in all detailed characters with the original description of the above species were collected in the State of Oaxaca by Lucius C. Smith in the Calderon, San Juan del Estado, 1 June, 1894, no. 37; by E. W. Nelson, in the Valley of Oaxaca, altitude 1,540 to 1,600 m., 8 and 24 September, 1894, no. 1234; by C. G. Pringle, in ravines of hills near Oaxaca, altitude 1,750 m., 15 September, 1894, no. 4907; and by C. Conzatti and V. González, about the city of Oaxaca, altitude 1,550 m., 2 April, 1896, no 98. From Mr. Pringle's full and careful notes, the following additional characters may be given. Entire plant 3 to 4½ m. in height, tree-like in habit; trunk 2 to 2½ m. high, 1 to 2 dm. in diameter, trichotomously branched above, covered with a grayish brown bark, stout spines, and a scattered stellate pubescence: mature fruit green, globose, about 2 cm. in diameter: seeds 3 mm. long, oblique, compressed and scrobiculate.

Dicliptera Pringlei. Annual, herbaceous, 5 to 8 dm. high: roots fibrous: stems hexangular, somewhat furrowed, lineolate, puberulent upon the angles, swollen or constricted just above the nodes: leaves ovate to ovate-lanceolate, acuminate, acute, narrowed below into a slender petiole, entire, ciliate, lineolate with a few scattered hairs on either surface; petioles pubescent, 2½ to 3½ cm. long, becoming gradually shorter above: inflorescence much branched, open: heads on long slender pedicels, 1(-2)-flowered: outer bracts equal, elliptical, muticous,

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into a petiole (10 to 16 mm. long), punctate especially on the under surface, dark green above, paler beneath, glandular below on either side of the midrib at the base of the blade with 1 to 2 or 3 oblong-elliptic glands: inflorescence in terminal and axillary nodding spike-like racemes, 4½ to 11 cm. long; bracts minute, equal to or exceeding the pedicels, the latter about 1 mm. long, and jointed just below the flowers: calyx 2 mm. long, subtruncate, 5-nerved, somewhat 5-angled and ciliate: corolla about 5 mm. in length, tubular, 5-lobed, white or pinkish; tube broad, glabrous on the outer surface below, puberulent above, pubescent in the throat; lobes broad, oblong or rounded, pubescent on either surface: style glabrous. — Collected by C. G. Pringle, in the mountains near Lake Chapala, Jalisco, 16 December, 1889, no. 2442. Flowers fragrant. Distributed as *Gonzalea glabra*, Wats., n. sp., Proc. Am. Acad. xxv. 152.

Citharexylum ovatifolium. A soft woody shrub, 2 to 3 m. in height: branches tetragonal, minutely striate, pubescent: leaves membranaceous, ovate-acuminate, 8 to 12 cm. long, 3½ to 6½ cm. broad, obtuse, submucronate, abruptly narrowed at the base into a more or less winged pubescent petiole, entire or irregularly crenate-dentate, ciliate, pubescent upon either surface, dark green above, slightly paler beneath, usually provided with one or more large glands on the lower surface at the base of the blade on either side of the midrib: inflorescence in pubescent spike-like nodding or flexuous racemes, 5 to 12 cm. long, terminating the branches and branchlets: bracts about 1 mm. long, minute, subulate, equalling or slightly exceeding the short pubescent pedicels: calyx 3 mm. long, subtruncate or minutely and irregularly 5-dentate, ciliate, 5-nerved, and somewhat 5-angled, pubescent on the outer surface: corolla about 7 mm. long, tubular, 5-lobed, white; tube broad, about 4 mm. long, glabrous on the outer surface, densely pilose-pubescent in the throat; lobes subrotund, glabrous on either surface, strongly ciliate: style glabrous. — Collected by C. G. Pringle, in a wet wooded barranca above Cuernavaca, altitude 2,000 m., August–September, 1896, no. 6540. This species has much in common with the imperfectly known *C. Sessei*, D. Don, but as the latter species is so very obscure it seems best to regard Mr. Pringle's plant as distinct, especially as it does not accord in all details with the meagre description of Don's species.

Solanum (Morella) deflexum. An annual erect or ascending herb becoming slightly woody at the base: roots fibrous: stems 1 to 4½ dm. high, simple or much branched, terete, covered especially above with a spreading hirsute pubescence: leaves simple, solitary or in pairs of subequal size, 2 to 6 cm. long, one half as broad, ovate, acute or

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at the base with rounded basal lobes on either side, margin entire, finely ciliate, hirsute or hirsutish pubescent above, hirsute on the midrib and veins beneath, 5 to 9 cm. long, 2 to 4 cm. broad; petioles hirsute, 1 to 5 cm. long: inflorescence in axillary pedunculate subumbellate racemes, granulose or glandular, and interspersed with spreading hirsute hairs: peduncles 1 to 2 cm. long: bracts linear, subulate, hirsute: pedicels slender, 10 to 17 mm. long: buds oblong, oval, obtuse, pubescent: calyx-divisions oblong-linear, acutish, ciliate, hirsute on the outer surface, glabrous within, 3 to 4 mm. long, about 1 mm. broad: corolla 1½ to 2½ cm. in diameter, orange yellow, or yellow streaked with parallel greenish veins, outer surface pubescent, inner surface glabrous; lobes oblong-linear, obtuse or rounded, usually oblique and often with a slight notch at the apex, 6 to 10 mm. long, about 3 mm. broad; crown 5-lobed, lobes denticulate. — Collected by C. G. Pringle, on hills near Patzcuaro, State of Michoacan, 3 August, 1892, no. 5277; on a wet wooded barranca above Cuernavaca, altitude 2,000 m., 4 August, 1896, no. 6373; Pedigral (lava beds), Valley of Mexico, altitude 2,500 m., 25 August, 1896, no. 6437.

Lithospermum (Batschia) oblongifolium. Herbaceous from a woody perennial base: stems erect, sparingly branched, 3½ to 5 dm. high, covered with a spreading hirsute pubescence: leaves sessile, oblong or oblong-ovate, acute, entire, tuberculate-hispid above, with a scattered substrigose pubescence beneath (somewhat more dense upon the veins), 4 to 8½ cm. long, 1½ to 2½ cm. broad: flowers axillary, disposed in leafy one-sided racemes or scorpoid cymes, in fruit about 15 cm. in length: pedicels 4 to 8 mm. long: calyx deeply 5-parted, persistent; divisions linear, 1-nerved, hirsute-pubescent, 10 to 14 mm. long: corolla tubular, 5-lobed, gibbous at the throat, about 3 cm. long; tube pubescent on the outer surface, inner surface glabrous except along five lines in continuance with the short filaments; lobes erect, subreniform, 3 mm. long, 5 mm. broad: style filiform, glabrous, more or less persistent; stigma capitate-2-lobed: nutlets ovate, acute, smooth, white, or white below and brownish above. — Collected by C. G. Pringle, on the Serrania de Ajusco, altitude 3,000 m., 18 August, 1896, no. 6451. A species with the habit of *L. Palmeri*, Wats., but readily distinguished by the pubescence of the stem and by the characters of the corolla and stigma.

Citharexylum glabrum. A tree 6 to 8 m. in height, glabrous throughout: branches and branchlets subterete, striate, covered with a brownish bark: leaves oblong to oblong-lanceolate, 4 to 10 cm. long, 1 to 3 cm. broad, rounded, obtuse or acute at the apex, narrowed at the base

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late, oblong-ovate to broadly ovate, 4 to 8 cm. long, 2 to 5 cm. broad, short-acuminate, entire, usually cordate at the base, finely pubescent upon either surface, especially upon the prominent midrib and the strongly reticulate veins beneath, above dark green, paler beneath: petioles canaliculate, 1 to 3 cm. long, puberulent or finely pubescent, bearing at their bases 2 or more small subulate stipule-like structures: inflorescence in axillary pedunculate minutely pubescent cymes; peduncle 2 cm. or more long; pedicels 1 to 1½ cm. long; calyx deeply 5-parted; divisions lance-linear, acute, about 4 mm. in length: corolla salverform, greenish yellow or sometimes purple; tube 22 mm. long, strongly contorted at the middle, provided at the orifice with an adnate subcuneate crown and bearing on the inside just above the attachment of the stamens a tuft of long villous hairs; lobes broadly obovate, 8 to 9 mm. long: anthers pubescent on the outer surface: carpels villous-pubescent: fruit reaching a length of 3 dm.; seeds about 2 cm. long. — Collected by C. G. Pringle, on lava beds near Cuernavaca, altitude 1,600 m., 23 September, 1896, no. 6554.

Astephanus pubescens. Stems slender, twining, finely striate, pubescent: leaves short-petiolate, lanceolate to ovate-lanceolate, 1½ to 6 cm. long, 4 to 20 mm. broad, acute at the apex or sometimes submucronate, obtuse at the base, entire, sparingly pubescent on either surface: petioles 2 to 4 mm. long, pubescent: inflorescence in subumbellate short-pedunculate several flowered axillary clusters; peduncles 1 to 2 mm. long: flowers on slender pubescent pedicels, the latter about 3 mm. in length: calyx minute, 5-parted, pubescent on the outer surface, provided on the inside with 5 small oblong glands alternating with the lobes: divisions ovate, acutish: corolla subcampanulate, about 3 mm. in diameter, deeply 5-lobed, white or tinged with brownish purple: lobes dextrorsely convolute in the bud, oblong, emarginate at the apex, spreading, later becoming somewhat reflexed, the upper inner surface, as well as the corolla-tube inside, granular or almost lepidote: fruit not seen. — Collected by C. G. Pringle, on a wet barranca above Cuernavaca, altitude 2,000 m., 21 September, 1896, no. 6507, and in the mountains near Cuernavaca, 3 August, 1896, no. 7203. A plant with the habit of *Metastelma*, or of *Vincetoxicum*, but by the entire absence of a crown, or at most by a very rudimentary one, its affinity is rather with the genus *Astephanus*, notwithstanding the presence of the minute glands at the sinuses on the inside of the calyx.

Gonolobus chrysanthus. Stems twining, greenish purple, granulose, interspersed with spreading or subreflexed hirsute pubescence: leaves ovate-oblong, acuminate, obtusish at the apex, a deep narrow open sinus

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much branched from a suffrutescent base, rather densely covered with a spreading villous pubescence: involucre purple, glabrous: capsule pubescent. — Collected by C. G. Pringle, Pedrigal (lava beds), Valley of Mexico, altitude 2,300 m., 25 August, 1896, no. 6436.

Mentzelia Conzattii. Stems whitish, covered with a thin scarious bark, below glabrous, above pubescent: lower leaves subopposite, upper alternate, simple, including the petioles 5 to 14 cm. long, 1½ to 3½ cm. broad, oblong-lanceolate, acuminate, acute, finely dentate, gradually narrowed at the entire base into a short petiole, scabrous above, tomentose beneath, midrib somewhat depressed above, prominent beneath; petioles 4 to 12 mm. long: inflorescence cymose-paniculate: flowers large, about 5 cm. in diameter, showy: calyx deeply 5-lobed; tube turbinate, barbellate-pubescent; lobes lance-ovate, acuminate, 12 mm. long, 4 mm. broad at the base, pubescent: corolla pentapetalous; petals ovate-oblong, short-acuminate, a little narrowed at the base, 2½ cm. long, 1 to 1½ cm. broad, yellow in the dried state: stamens disposed in phalanges opposite the petals, the filaments of the 3 outer stamens of each phalanx somewhat flattened, the others filiform: style single, filiform; stigma terminal: mature fruit not seen. — Collected by C. Conzatti, Oaxaca, altitude 1,500 m., 5 January, 1896, no. 62.

Streptotrachelus, nov. gen. of *Apocynaceæ* (*Euechitideæ*). Calyx 5-parted, naked at the base within. Corolla salverform, coronate, esquamate, tube cylindrical not dilated at the throat, soon becoming strongly contorted at the middle; lobes 5, dextrorsely convolute in the bud, and sinistrorsely twisted. Stamens affixed to the upper half of the corolla-tube, included, free portion of the filament short; anthers sagittate, acuminate, connivent about the stigma, the cells projecting below into two rigid appendages. Disk of 5 oblong fleshy persistent scales about equalling the ovary. Ovary of two distinct carpels with a common filiform style; stigma fleshy, oblong-cylindrical, short-acuminate, somewhat 2-cleft at the apex, dilated at the base, adherent above and below to the anthers; ovules in each carpel numerous. Follicles subterete. Seeds oblong-linear, furrowed, not contracted into a beak at the coma-bearing apex; albumen scanty; cotyledons plane. Woody stemmed twining plants with opposite leaves and cymose inflorescence. The generic name is taken from στρεπτός, twisted, and τράχηλος, throat, in reference to the twisting of the corolla-tube.

Streptotrachelus Pringlei. Stems woody, more or less covered with lenticels, twining and clambering over shrubs and small trees to 4 or 6 meters; branchlets reddish brown, puberulent: leaves opposite, petio-

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Bletia macristhmochila. Bulbs terrestrial, subglobose or somewhat gibbous: scape 6 to 6½ dm. high, surrounded at the base by 4 to 6 purplish striated acute sheaths, naked portion smooth, 1–2-vaginate, terminating above in a few-flowered raceme: leaves plicate, broadly lance-acuminate, smooth, about 7-nerved, 12 to 30 cm. long, 2 to 4 cm. wide: bracts triangular-acuminate, 10 to 14 mm. long: flowers 5 to 8 cm. in diameter, rose-purple in the dried state: sepals oblong, short-acuminate, a little narrowed at the base, 3 to 4 cm. long, 10 to 12 mm. broad: petals oblong, obtuse or rounded at the apex, rather abruptly narrowed below, considerably broader than the sepals; labellum deeply 3-lobed, lateral lobes broad and obtusely triangular, strongly flabellate-nerved, the upper nearly horizontal margins subcrenate, lateral margins entire, median lobe deeply obcordate, apiculate in the terminal sinus, the two spreading subcrenulate or erose lobes narrowed below, and connecting with the lateral lobes by a long narrow neck or isthmus; lamellæ 5, strongly undulate, continuous from near the apex almost to the base of the labellum: gynœcium narrowly winged, 2 to 2½ cm. long. — Collected by Dr. E. Palmer, on a barranca, near Guadalajara, June, 1886, no. 127, also by C. G. Pringle, in the same locality, 2 July, 1889, no. 2875. This plant has been confused with *B. campanulata*, Llav. & Lex., to which species it was referred by Dr. Sereno Watson. It may however be distinguished from *B. campanulata*, as well as from *B. fulgens*, Reichb., a large flowered species growing in similar localities, by the long narrow neck or isthmus of the labellum.

Microstylis streptopetala, Rob. & Greenm. Proc. Am. Acad. xxxii. 36. A large flowered form of this species was collected by C. G. Pringle, on lava beds, Serrania de Ajusco, at an elevation of 2,400 m., August, 1896, no. 6410. Except in the size of the flowers, which are about one third larger than in the type, the specimens agree in every detail with the above species.

Aristolochia longecaudata, Watson, var. virescens. Perennial from a ligneous base: stems decumbent or prostrate, sulcate, somewhat retrorsely hirsute-pubescent: leaves ovate to ovate-oblong, often acuminate, pubescent on either surface, 3–5-nerved, 3 to 9 cm. long, 1½ to 5½ cm. broad: petioles 1 to 3½ cm. long. — Collected by C. G. Pringle, about Cuernavaca, altitude 1,500 m., 23 July, 1896, no. 6383. A form differing from the type of the species by its larger thinner and less pubescent leaves, but having the same technical characters in flower and fruit.

Euphorbia ramosa, Seaton, var. villosior. Stems decumbent,

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Agave (Euagave) collina. Acaulescent: leaves 30 to 40 in a rosette, linear-attenuate, 6 to 8 dm. long, 2 cm. broad just above the base, 2½ cm. broad at the middle, gradually narrowed to the apex and terminated by a reddish brown spine (2 cm. or more long), margin narrowly cartilaginous bearing reddish brown straight or curved teeth (3 to 5 mm. long) at intervals of 8 to 18 mm., upper surface concave, below convex, bluish green: peduncles 3 to 4 m. long: panicle 6 to 8 dm. long, the lower branches about 3 dm. long: flowers greenish yellow, including the stamens, 9 cm. long: tube of the perianth 1½ cm. long, funnel-shaped; segments linear-oblong, obtuse, thickened at the apex, about 2 cm. long: stamens more than twice as long as the perianth-segments; filaments flattened, glabrous, about 5 cm. long from the point of insertion; anthers 2½ to 3 cm. in length: style overtopped by the anthers: fruit a loculicidal capsule, 4½ to 5 cm. long, 2½ to 3 cm. in diameter; seeds obliquely triangular, about 1 cm. long. — Collected by C. G. Pringle, on hillsides near Cuernavaca, altitude 1,500 m., 1896, no. 6349. This may prove eventually to be identical with the imperfectly known species *A. serratula*, Karw., but as the flowers and fruit of the latter are unknown, and our plant does not agree in all details with the fragmentary description of Karwinski, it seems best to regard Mr. Pringle's plant as a distinct species.

Nemastylis cærulescens. Bulb ovoid, 1½ to 2 cm. in diameter, covered with dark brown scales: stem or scape 14 to 20 cm. high, branched above, bearing 1 to 3 pedunculate spathes: the outer radical leaves much reduced, the inner a single linear-attenuate leaf, 10 to 15 cm. long, usually exceeding the scape; stem leaves reduced to lance-attenuate bracts, 3 to 4½ cm. long, subtending the inflorescence or pedunculate spathes: peduncles 1 to 2½ cm. in length: bracts of the spathe linear-oblong, acuminate, the outer 2 to 3 cm. in length, the inner a little longer: pedicels slender, 2½ to 3½ cm. long: flowers white, sometimes with a faint shade of blue, 3½ to 4½ cm. in diameter, becoming reflexed; divisions of the perianth flabellate-nerved, hirtellous-puberulent above near the base, the outer oblong-elliptic, about 6 mm. broad, the inner somewhat smaller and a little narrowed toward the base: filaments united at the base, free portion flattened, about 2 mm. long; anthers 1 cm. in length, curling with age: capsule smooth, obovoid, subtruncate above, 7 to 10 mm. long, 5 to 7 mm. in diameter: seeds irregularly angled, yellowish, minutely pitted, 2 mm. long. — Collected by C. G. Pringle, on dry gravelly soil near Cuernavaca, altitude 1,600 m., June, 1896, no. 6324. A species most nearly related to *N. acuta*, Herb. (*N. geminiflora*, Nutt.), but a much smaller plant and with different flowers.

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III. — DESCRIPTIONS OF NEW AND LITTLE KNOWN PLANTS FROM MEXICO.

Tradescantia macropoda. Roots tuberous, fascicled: stems erect or suberect, sparingly branched, bilineate-pubescent, otherwise glabrous or puberulent: leaves oblong-ovate, acute, 5 to 8 cm. long, 1½ to 2½ cm. broad, abruptly narrowed below to an unequal base, glabrous or sometimes inconspicuously puberulent on either surface; margin, except at the ciliated base, hispidulous: sheaths 5 to 8 mm. long, puberulent, especially along the line of pubescence on the stem, strongly ciliate: inflorescence umbellate on rather long slender peduncles (2 to 4½ cm. long): bracts orbicular-ovate, obtuse, glabrous, 5–7-nerved: flowers several, fugitive in the bracts; calyx-divisions oblong, navicular, thin or scarious, 1-nerved, 3 to 4 mm. long, one half as broad; the outer sepal often sparingly long hirsute-pubescent on the keel: corolla light purple in the dried state; petals about 6 mm. long, two thirds as broad: stamens 6, equal; filaments somewhat exceeding the corolla, rather scantily covered toward the base with multicellular hairs; anther-cells globose, equal, widely separated by a long narrow connective: ovary glabrous or with a few scattered glandular hairs at the apex: seeds light brown, transversely rugose. — Collected by C. G. Pringle, on moist banks of mountains above Cuernavaca, altitude 2,000 m., 3 August, 1896, no. 6402. A species nearly related to *T. commelinoides*, Rœm. & Schult., but readily separated by the nearly glabrous character throughout, and by the long slender glabrous peduncles.

Schœnocaulon Pringlei. Bulbs ovoid, 1 to 2 cm. in diameter: caudex erect, cylindrical, 3 to 10 cm. long, surrounded by a covering of dark brown fibres, the remnants of the bulb-scales and outer leaves: foliar leaves linear-attenuate, 1 to 5 dm. long, 2 to 6 mm. broad, 9–10-nerved, smooth on either surface, margin slightly roughened: naked scape 3½ to 6 dm. high, terete or slightly flattened, smooth: inflorescence dense, 3 to 8 cm. long, 1 cm. broad: bracts broadly ovate, acute, scarious, 2½ mm. long: divisions of the perianth oblong, about 4 mm. long, 3-nerved, obtuse or rounded at the slightly thickened apex, margins scarious, irregularly subdenticulate, or entire: stamens in anthesis about equal or slightly exceeding the divisions of the perianth (even in the later stages exceeding the perianth divisions by about 1 mm. only): immature capsules about 12 mm. long, erect, glabrous, rather dense, and somewhat appressed to the rhachis. — Collected by C. G. Pringle, on lava beds, Serrania de Ajusco, altitude 2,400 m., 23 August, 1896, no. 6415.

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Var. hypoleucum. Leaves ovate-oblong, acuminate, glabrous above, white-tomentose beneath, more or less glabrescent. — Collected by C. G. Pringle, in cañons near Guadalajara, 8 December, 1888, no. 2169, and on rocky banks of river below the Falls of Juanacatlan near Guadalajara, 25 October, 1889, no. 2372, the latter distributed as *Liabum discolor*, Benth. & Hook. f.

The companion number cited by Hemsley, Bourgeau, no. 1401, as represented in the Gray Herbarium, shows an arachnoid pubescence still adhering to the under surface of the leaves. Pringle's no. 2169 shows the tomentum on the lower surface of the leaves to be evanescent; this number, however, certainly represents the same species as Pringle's no. 2372, which has a dense tomentum on the lower surface of the leaves. It seems best therefore to regard these two specimens collected by Mr. Pringle as a tomentose variety of *Liabum glabrum*, Hemsl. Mr. Pringle's no. 6182, collected in the type locality, is probably more typical of the species proper.

†† Involucral bracts acute: immature achenes setulose at the apex.

L. sericolepis, Hemsl. l. c.

†† Inflorescence in thyrsoid panicles, terminating the stems and branches: involucral scales lance-attenuate: pappus of unequal setæ, not biseriate.

L. Klattii, Rob. & Greenm. Am. Jour. Sci. ser. 3, L. 156.

††† Heads few, large, 2 cm. or more in diameter: involucre multiseriate; scales lanceolate, acute: petioles short, about 4 mm. in length.

L. Pringlei, Rob. & Greenm. Proc. Am. Acad. xxxii. 49.

*** Leaves sessile, linear or palmately lobed: heads discoid, few, on long peduncles: involucral scales linear-attenuate: achenes sericeous.

† Leaves amplexicaul, palmately lobed.

L. cervinum, Rob. Proc. Am. Acad. xxix. 317.
L. Palmeri, Gray, Proc. Am. Acad. xxii. 432.

†† Leaves linear, subverticillate.

L. angustissimum, Gray, l. c.

**** Species of doubtful affinity.

L. Liebmannii, Klatt, Leopoldina, xxiii. (reprint, p. 7). From the very meagre characterization of this species it is impossible to give its exact affinity without seeing Liebmann's specimen.

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Nov. Gen. & Spec. iii. 386; Bot. Mag. 4223. *Æginetia longiflora*, Cav. Ic. vi. 51, t. 257, f. 1.

H. (MACROHOUSTONIA) TRIFLORA, Gray, l. c., Hemsl. l. c., is a good *Bouvardia*.

From the technical characters of complete specimens of the last two species, now at hand, there seems no reason for retaining them in the genus *Houstonia*.

II. KEY TO THE MEXICAN SPECIES OF LIABUM.

* Leaves ovate or ovate-deltoid: heads radiate.

← Leaves ovate-deltoid, more or less deeply sinuate-dentate and mucronate-denticulate: heads few, large (3 to 5 cm. in diameter), terminating the stem.

L. Andrieuxii, Benth. & Hook. f. Gen. ii. 437. *Vernonia Andrieuxii*, DC. Prodr. v. 16.

← ← Leaves ovate, entire or mucronate-denticulate: heads disposed in terminal panicles.

↔ Pappus of slender unequal setæ, not biseriate.

= Involucral scales lance-attenuate: petioles winged and often dilated about the stem: ligules narrow: achenes pubescent.

L. asclepiadeum, Schz. Bip. Linnæa, xx. 521.

= = Involucral scales oblong, obtuse: ligules ovate: achenes glabrous.

L. polyanthum, Klatt, Bull. Soc. Bot. Belg. xxxi. (1892), 209.

↔ ↔ Pappus distinctly biseriate, outer series short, paleaceous.

= Achenes pubescent.

L. andromachioides, Benth. & Hook. f. Gen. ii. 436. *Vernonia andromachioides*, Less. Linnæa, vi. 397, 645.

L. Deppeanum, Hemsl. Biol. Centr.-Am. Bot. ii. 232. *Andromachia Deppeana*, Less. Linnæa, vi. 401.

= = Achenes glabrous.

L. platylepis, Schz. Bip. Flora, 1856, 160; Klatt, Leopoldina, xxiii. (reprint, p. 7).

L. discolor, Benth. & Hook. f. Gen. ii. 436. *Sinclairia discolor*, Hook. & Arn. Bot. Beech. 433; Hook. Ic. Pl. v. t. 451.

* * Leaves ovate or ovate-lanceolate: heads discoid.

← Inflorescence in loose terminal pyramidal panicles: involucre 3–5-seriate: pappus biseriate.

↔ Immature achenes stipitate-glandular: involucral scales obtuse.

L. glabrum, Hemsl. l. c.

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scrobiculate. — Proc. Am. Acad. xvii. 203. — In the mountains, 24 miles N. E. of Monclova, Coahuila, Palmer, nos. 404, 406; Santa Eulalia Mountains, Chihuahua, Pringle, nos. 151, 354; adjacent Texas, at Presidio, Bigelow, in Mexican Boundary Survey; foothills of Chisos Mountains, Havard, No. 31; and in the Organ Mountains, New Mexico, Vasey, 1881.

← ← Leaves 3 to 18 mm. in length: corolla 10 to 14 mm. long.

H. fruticosa, Rose. Low much branched shrub, glabrous throughout: stem and branches covered with a rough yellowish brown or grayish bark: leaves linear or somewhat thickened and subterete, submucronate, more or less fascicled in the axils; stipules short, glandular-setiferous: inflorescence in terminal rather few-flowered dichotomous cymes; flowers subsessile or short pedicellate: calyx deeply 5-lobed with a single stipitate gland in each sinus; lobes linear-lanceolate, about 3 mm. long, foliaceous: corolla about 3 times longer than the calyx; tube narrowly funnel-shaped, glabrous: capsule short, oblong, subtruncate or slightly emarginate; seeds oblong, peltate, concavo-convex, minutely scrobiculate. — Contrib. U. S. Nat. Herb. i. 132, 239. *Hedyotis* (*Ericotis*) *mucronata*, Benth. Bot. Sulph. 19. — Magdalena Island, Lower California, Brandegee, 17 January, 1889; Carmen Island, Palmer, no. 885.

§ 3. Macrohoustonia. Erect shrubby plants with ovate leaves and rather large flowers. — Gray, Proc. Am. Acad. iv. 314. A section scarcely to be retained.

H. bouvardioides, Benth. & Hook. f. Shrub 3 to 4 feet high: stems terete, granular-puberulent: leaves opposite or ternate, short-petiolate, ovate or elliptic-lanceolate, acute or short-acuminate, entire, finely puberulent upon either surface, especially upon the midrib and veins: inflorescence in terminal compound minutely pubescent cymes: calyx deeply 4-parted; divisions linear, 3 mm. long: corolla funnelform, about 12 mm. long, glabrous, rather deeply 4-lobed; tube with a few scattered hairs on the inside toward the base; lobes oblong, obtuse: anthers long-exserted: style included (probably dimorphous); ovules rather numerous: seeds not seen. — Gen. ii. 60; Hemsl. Biol. Centr.-Am. Bot. ii. 30. *Hedyotis* (§ *Anotis*) *bouvardioides*, Seem. Bot. Herald, 296, t. 64. — N. W. Mexico, Seemann. A plant having much more in common with *Bouvardia* than with *Houstonia*, but without fruit or mature seeds it seems unwise to make the transfer. More complete specimens, however, may justify its removal to the former genus.

H. (Macrohoustonia) longiflora, Gray, Proc. Am. Acad. iv. 314, Hemsl. Biol. Centr.-Am. Bot. ii. 30, is *Bouvardia longiflora*, HBK.,

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at the throat, almost funnelform: capsule about two thirds inferior, globose or short-oblong, obtuse or slightly retuse, pubescent, much exceeded by the erect persistent calyx-divisions; seeds more or less crateriform, somewhat roughened on the back. — Proc. Am. Acad. xvii. 203, & Syn. Fl. N. A. i. pt. 2, 27; Hemsl. Biol. Centr.-Am. Bot. iv. 47. *Hedyotis* (*Ereicotis*) *acerosa*, Gray, Pl. Wright. i. 81. *Oldenlandia* (*Ereicotis*) *acerosa*, Gray, Pl. Wright. ii. 67. *Mallostoma acerosa*, Hemsl. Biol. Centr.-Am. Bot. ii. 31. — Northern Mexico, Parry, nos. 7, 302, Gregg, no. 72, Palmer, nos. 400, 401, 402, 403; adjacent Texas, Wright, nos. 237 (type), 1118, Thurber, no. 91, and Bigelow.

H. polypremoides, Gray. Low, cespitose, 6 to 15 cm. high, much branched from a woody perennial base: stems strict, ascending or erect, usually branched above, glabrous or densely hirtellous-puberulent: leaves less fascicled than in the preceding species, acerose-linear, 5 to 10 mm. long, glabrous or hirtellous, margin revolute, often ciliate, midrib thickened: flowers dimorphous, sessile or distinctly pedicellate, terminating the stems and branches; pedicels elongated in fruit, reaching a length of 13 mm.: calyx-divisions awl-shaped, 3 to 4 mm. long: corolla salverform or slightly funnelform, "white changing to purple," 8 to 10 mm. long: capsule globose, about two thirds inferior; seeds open-crateriform, oblong-rotund with a short hilar ridge. — Proc. Am. Acad. xxi. 379. — Chihuahua, Santa Eulalia Mountains, Pringle, nos. 16, 356; on route from Leavenworth to El Paso, F. R. Diffenderffer; at junction of Delaware Creek and Pecos River, Texas, Pope.

Var. Bigelovii. A form with the calyx-lobes 1½ to 2 mm. long, otherwise as in the type. — Florence Mountains, Bigelow, in the Mexican Boundary Survey, June, 1852, no. 437.

* * Distinctly shrubby, 2½ dm. or more high, much branched: leaves thickish, more or less fascicled: inflorescence in cymes terminating the stems and branches.

← Leaves 3 to 10 mm. in length, much fascicled: corolla 3 to 4 mm. long.

H. fasciculata, Gray. A low bushy shrub, much branched: stem and branches covered with a grayish bark: branchlets tetragonal, hirtellous-puberulent: leaves linear, subterete, thick, rigid, nearly equalling the internodes, decidedly fascicled in the axils, glabrous or hirtellous, margin revolute; stipules short, scarious, 1 to 3 setiferous-dentate: cymes few-flowered: flowers small, "white, drying purple," dimorphous: calyx-divisions short, about 1 mm. long, obtuse, usually puberulent: corolla deeply 5-lobed; lobes recurved; tube long-pilose-pubescent on the inner surface: capsule oblong; seeds oblong, peltate, concavo-convex, minutely

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rotund with a longitudinal hilar ridge on the ventral surface, scrobiculate. — Proc. Am. Acad. xvii. 202. — Northern Mexico, Coahuila, in the region of Saltillo, Palmer, nos. 397, 398, and in the same State on limestone hills, Carneros Pass, Pringle, no. 2381.

†† †† Leaves much reduced: capsule about 2 mm. long.

H. longipes, Watson. Erect, much branched, 1 to 2½ dm. high: stems and branches subterete, slender, glabrous or below granular-hirtellous: leaves linear-filiform, 4 to 10 mm. long, glabrous; stipules minute: flowers small, "whitish and yellowish," 8 mm. long, on slender filiform pedicels: calyx-divisions linear, about 1 mm. long, obtusish and submucronate: corolla funnelform, upper portion of tube pubescent within; lobes pilose-pubescent above: capsule small, subrotund; seeds saucer-like or subcrateriform with a longitudinal ridge on the hilar surface, scrobiculate. — Proc. Am. Acad. xviii. 97. — Near Monclova, Coahuila, Palmer, no. 394, and by the same collector at Monterey, Nueva Leon, no. 395; also by Dr. Gregg at Cerralbo, collected 29 May, 1847.

H. brevipes, Rose. A low much branched distinctly suffrutescent plant, 2 to 3 dm. high, glabrous throughout, somewhat glaucous: branches slender, terete: leaves linear-filiform, 10 to 15 mm. long; stipules short, 1–4-setiform: flowers sessile or on slender pedicels: calyx deeply 4-lobed, with a stipitate gland in each sinus: divisions in anthesis about 1 mm. long: corolla salverform, 10 to 15 mm. long; tube slender, slightly enlarged above; lobes glabrous above: capsule subglobose; seeds oblong, peltate, cancavo-convex, minutely scrobiculate. — Contrib. U. S. Nat. Herb. i. 83, 132. — Lower California, Santa Rosalia, Palmer, no. 202; Carmen Island, Palmer, no. 836; also specimen in Gray Herbarium from Lower California, apparently from the herbarium of Dewey, without further data.

§ 2. Ereicotis. Fruticose or fruticulose plants with linear subterete rigid-setaceous or acerose-linear leaves: capsule short-oblong, obtuse or retuse; seeds open-crateriform or oblong, peltate, minutely scrobiculate. — Gray, Proc. Am. Acad. xvii. 203.

* Low, 2 to 18 cm. high, much branched from a woody perennial base: leaves rigid-setaceous or acerose-linear.

H. acerosa, Gray. A low diminutive cespitose shrub: branches ascending or erect, strict, striate, hispidulous: leaves opposite or in threes or fours, 5 to 12 mm. long, connected at the base by a stipular setiferous cup, more or less hispid and ciliate: flowers sessile at the ends of the branches and branchlets: calyx deeply 4-parted; divisions setaceous, 4 mm. long, hispidulous: corolla-tube slender, about 1 cm. long, dilated

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basal leaves narrowly spatulate, 5 to 8 mm. long; the upper gradually narrowed, hispidulous-puberulent above, glabrous beneath: pedicels elongated, filiform: flowers small, 4 to 6 mm. long: calyx-divisions short, scarcely 1 mm. in length, obtuse: corolla funnelform: capsule subglobose, 1½ mm. long. — Contrib. U. S. Nat. Herb. i. 70. — Lower California, La Paz, Palmer, no. 31.

H. asperuloides, Gray. Much branched from the base, 5 to 18 cm. high: branches divaricately spreading and ascending, inconspicuously hispidulous-puberulent or quite glabrous: leaves linear or a little dilated above the middle, 5 to 24 mm. long, glabrous: flowers on slender filiform pedicels: calyx-lobes lance-linear, 1½ to 2 mm. long, acute, slightly unequal: corolla funnelform, about 8 mm. long; tube below puberulent on either surface: capsule clavate-turbinate, tapering below; seeds oblong, peltate, somewhat concavo-convex, minutely scrobiculate. — Proc. Am. Acad. v. 158; Rose, Contrib. U. S. Nat. Herb. i. 70. *Hedyotis* (*Ericotis*) *asperuloides*, Benth. Bot. Sulph. 19, t. 13. — Lower California, Cape St. Lucas, Xantus, no. 43; at La Paz, Palmer, nos. 24, 31ª; and by Brandegee, 5 February, 1890, the latter distributed as *Houstonia Brandegeana*, Rose.

H. arenaria, Rose. Erect or ascending, glabrous throughout: stems much branched: upper leaves linear or linear-lanceolate, 1½ to 2 cm. long: stipules short, scarious, laciniate: inflorescence in loose terminal dichotomous cymes with the terminal flower sessile: calyx-lobes about 1 mm. long, obtusish, inconspicuously serrulate on the margins: corolla about 4 mm. long, funnelform; lobes spreading, broadly ovate: capsule obcordate-compressed, 1½ mm. long; seeds oblong, peltate, slightly concavo-convex, scrobiculate. — Contrib. U. S. Nat. Herb. i. 70. — Lower California, La Paz, Palmer, no. 28; San Jose del Cabo, Brandegee, no. 261.

+ + Low dichotomously branched perennials: stems becoming slightly woody below: ovary one half to three fourths inferior: capsule short-oblong or subglobose.

++ Stems rather leafy: capsule about 3 mm. long.

H. Palmeri, Gray. Erect, profusely branched: branches hirtellous-puberulent or glabrous: leaves linear-filiform, glabrous, 5 to 18 mm. long; stipules small, subtruncate, minutely dentate, or triangular-acute: pedicels slender, erect or ascending: flowers about 1 cm. long, dimorphous: calyx-divisions lance-linear, 2 mm. long, ciliate: corolla salver-shaped or slightly funnelform, upper portion of tube pubescent within: free portion of capsule often hirtellous; seeds open-crateriform, oblong-

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no. 26; region of San Luis Potosi, altitude 1,800 to 2,460 m., Parry & Palmer, no. 300; hills and plains near Chihuahua, Pringle, no. 274; Sonora, south of San Luis, Parry, no. 6; Thurber, nos. 319, 707; without locality, Coulter, no. 196; New Mexico, Fendler, no. 291, Wright, no. 1119, Palmer, no. 93; Arizona, Wolf & Rothrock, no. 865; in the Huachuca Mountains, Lemmon, no. 2725, at Bisbee, F. E. Lloyd.

+ + Distinctly annual: stems dichotomously branched: corolla funnelform.

H. humifusa, Gray. A low annual: stems dichotomously branched, hispidulous: leaves linear or the lower oblanceolate, 1 to 1½ cm. long, 1 to 5 mm. broad, mucronate, hispidulous above, margins revolute: stipules broad, scarious, and setiferous: flowers axillary, rather numerous above: calyx-divisions setaceous-subulate, 3 to 4 mm. long: corolla open-funnelform, 6 to 7 mm. long; lobes pubescent above: pedicels strongly recurved in fruit: capsule depressed-globose, subdidymous. — Proc. Am. Acad. iv. 314. *Hedyotis* (*Houstonia*) *humifusa*, Gray, Pl. Lindh. ii. 216. — New Mexico, Thurber, no. 292; Texas, Lindheimer, nos. 621, 622, 377, 378; E. Hall, no. 286; on sandy prairies near Austin, Wright; Belknap, Sutton Hayes, no. 333; Colorado City, Reverchon, no. 60; on sandy hills and plains near Sweetwater, Curtiss, no. 1140; also specimen cultivated in the Cambridge Botanic Garden in 1849.

* * * A low slender leafy stemmed annual, with small white flowers on spreading axillary pedicels: capsule three fourths inferior.

H. subviscosa, Gray. A delicate herb, 4 to 15 cm. high: stems branched from the base: branches spreading, covered with a subviscid hirtellous pubescence: leaves linear-filiform, 5 to 15 mm. long, glabrous or hirtellous: stipules short, scarious, minutely setulose-ciliate: pedicels filiform, 3 to 8 mm. long, horizontally spreading but scarcely reflexed in fruit: calyx hirtellous-pubescent; divisions acute, about 1 mm. long: corolla salverform, about 3 mm. long: capsule subdidymous, broader than long; seeds open-crateriform, minutely scrobiculate. — Proc. Am. Acad. iv. 314. — *Oldenlandia subviscosa*, Wright in Gray, Pl. Wright. ii. 68. — Southern Texas, Berlandier, nos. 991, 2421, and Wright, without number.

* * * * Slender diffuse herbs, or perennials, 5 to 25 cm. high: stems more or less dichotomously branched, often becoming slightly woody below: leaves linear, subterete or filiform, shorter than the internodes: pedicels erect or spreading in fruit.

+ Low delicate annuals: calyx adnate nearly to the top of the ovary: capsule clavate-turbinate or subglobose.

H. Brandegeana, Rose. Erect or ascending, 5 to 10 cm. high, freely branching from the base: stems filiform, hispidulous-puberulent:

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angustifolia, Michx., var. *rigidiuscula*, Gray, Syn. Fl. N. A. i. pt. 2, 27, in part. — Corpus Christi, Texas, Palmer, without number, collected in 1879; Heller, no. 1812.

* * Low-tufted leafy species, 2 to 12 cm. high: pedicels reflexed in fruit: capsule one fourth inferior; seeds open-crateriform, oblong-rotund, with a median longitudinal ridge on the hilar surface.

+ Distinctly perennial, multicipital from a deep ligneous root.

H. Wrightii, Gray. Stems quadrangular, pruinose-puberulent: leaves linear or the lower narrowly spatulate, thickish, glabrous; stipules rather pronounced, broadly deltoid, entire or minutely denticulate: flowers dimorphous, 5 to 7 mm. long, in terminal leafy cymes: calyx-divisions lance-linear, acute, 1½ to 2 mm. long, glabrous: corolla salver-shaped; tube 2½ to 4 mm. long (depending upon the long- or short-styled form respectively), slightly enlarged above: seeds scrobiculate. — Proc. Am. Acad. xvii. 202, & Syn. Fl. N. A. i. pt. 2, 26. *H. humifusa*, Hemsl. Biol. Centr.-Am. Bot. ii. 30, not Gray. *Hedyotis* (*Houstonia*) *humifusa*, Gray, Pl. Wright. i. 82. *Oldenlandia* (*Houstonia*) *humifusa*, Gray, Pl. Wright. ii. 68, excl. syn. — State of Mexico, in meadows on the Sierra de las Cruces, elevation 3,000 m., Pringle, no. 5744; on the Serrania de Ajusco, altitude 3,000 m., Pringle, no. 6468; San Luis Potosi, elevation 1,800 to 2,460 m., Parry & Palmer, no. 301; in the vicinity of the city of Durango, Palmer, no. 312; Chihuahua, on the summits of Sierra Madre, Pringle, no. 2284; and on dry mountain sides, Chuchuichupa, in the same State by C. V. Hartman, no. 705; New Mexico, Wright, no. 241, Thurber, nos. 717, 1121; Santa Magdalena Mountains, Vasey; near Santa Rita del Cobre, E. L. Greene; Arizona, at Fort Whipple, Coues & Palmer, no. 75; in the San Francisco Mountains near Clifton, E. L. Greene; Prescott, Dr. Smart, no. 460; Lemmon, nos. 2726, 512, 512½; in the Rincon and Santa Rita Mountains, Pringle; at Willow Spring, Palmer, no. 523.

H. rubra, Cav. Much depressed, rather dense, 2 to 10 cm. high: stems and leaves hispidulous or nearly glabrous: leaves linear, or the lower oblanceolate-linear, 5 to 25 mm. long; stipules short with one or more setæ: flowers 1½ to 2½ cm. long, axillary: calyx-divisions linear, acute, in anthesis 2 mm. long, in fruit somewhat elongated: corolla red or purple varying to white; tube slender: capsule depressed, subrotund; seeds scrobiculate. — Ic. v. 48, t. 474, f. 1; Benth. Pl. Hartw. 15; Hemsl. Biol. Centr.-Am. Bot. ii. 30; Gray, Syn. Fl. N. A. i. pt. 2, 25. *Oldenlandia* (*Houstonia*) *rubra*, Gray, Pl. Wright. ii. 68. — Aguas Calientes, Hartweg, no. 93; Valley of San Luis Potosi, Schaffner,

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Key West, Blodgett; also Curtiss, no. 1137. Drummond's no. 116, and Havard's nos. 231, 232, from Texas, are somewhat intermediate between the species and variety.

Var. scabra, Wats. Flowers short-pedicellate: calyx somewhat hirsute-scabrous: corolla-lobes near the apex externally covered with hirsute hairs (especially in bud): capsule rather larger than in the species. — Proc. Am. Acad. xviii. 97. — Caracol Mountains, Coahuila, Palmer, no. 410; Monterey, Nueva Leon, Palmer, no. 2116.

Var. rigidiuscula, Gray. From 1 to 3 cm. high: leaves linear to linear-oblong, 1 to 2 cm. long, 1 to 5 mm. broad, rather rigid: pedicels somewhat shorter than in the species proper: calyx-divisions usually exceeding the free portion of the capsule. — Syn. Fl. N. A. i. pt. 2, 27, in part. — Carneras Pass, Coahuila, Pringle, no. 2855; Gregg, no. 66; Valley of San Luis Potosi, Schaffner, no. 614; Texas, Guadalupe Mountains, Havard, no. 233; Rio Brassos, Drummond, no. 73 (Florida, Rugel, no. 322, from Dr. Gray).

H. rupicola. Low, profusely branching from a woody perennial base: stems erect, 8 to 14 cm. high, 4-angled, glabrous: leaves linear, 5 to 15 mm. long, acute or submucronate, rather rigid: stipules triangular, acute or short acuminate, usually unequally setiferous-denticulate: flowers dimorphous, sessile or short-pedicelled, disposed in small cymules terminating the stems and branches: calyx-divisions small, acute, scarcely 1 mm. long: corolla narrowly funnelform, about 5 mm. long; lobes pubescent above: capsule globose, 1½ mm. or less in length, about one half inferior; seeds oblong, peltate, slightly concave on the hilar surface, scrobiculate. — *H. fasciculata*, Gray, Syn. Fl. N. A. i. pt. 2, 27, as to plant Wright. *Hedyotis* (*Amphiotis*) *stenophylla*, var. *parviflora*, Gray, Pl. Wright. i. 81. — Crevices of rocks on the San Pedro River, Arizona, Wright, no. 238.

++ Low, branching from the base: stems spreading or prostrate: divisions of the calyx obtuse.

H. salina, Heller. Low, spreading or prostrate: stems 8 to 10 cm. long, branching from a woody perennial base, glabrous: leaves oblong-linear, 5 to 15 mm. long, 2 to 5 mm. broad, essentially glabrous, margin volute: inflorescence in close subcapitate cymules terminating the stems and branches: flowers dimorphous: calyx-lobes short, scarcely 1 mm. long, obtusish, glabrous or hirtellous: corolla funnelform, 5 mm. long, pubescent in the throat; lobes pubescent above: capsule short-oblong, a little narrowed below, about three fourths inferior, the free portion about equalling the calyx-lobes; seeds as in the preceding species. — Contrib. Herb. Frank. & Marsh. Coll. no. 1, 96. *Houstonia*

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lous upon the angles: lower leaves oblanceolate; upper gradually narrowed to linear, 7 to 17 mm. long: stipules broadly ovate, scarious, minutely denticulate: flowers minute in the axils near the ends of the branches: pedicels 1 to 6 mm. long: calyx glabrous; lobes linear-oblong, acutish, spreading or recurved, 1½ to 2 mm. long: corolla white, equalling or slightly exceeding the lobes of the calyx; lobes erect, glabrous, about equalling the tube: capsule three fourths inferior; seeds open-crateriform, oblong-rotund, with a median hilar ridge. — Collected by J. E. Bodin, Round Rock, Texas, 10 March, 1890, no. 24.

+ + + Erect or low-spreading herbaceous perennials, 1 to 4 dm. high: leaves linear, linear-oblong, or ovate: inflorescence in terminal cymes: capsule obcordate-compressed, or oblong and a little nerved below, one half to three fourths inferior.

++ Erect herbaceous perennials: divisions of the calyx acute.

H. PURPUREA, L., Sp. Pl. i. 105, attributed to Mexico by Hemsley (Biol. Centr.-Am. Bot. ii. 30), apparently does not extend so far south. Gregg's no. 66, cited by Hemsley under the above species, is *Houstonia angustifolia*, Michx., var. *rigidiuscula*, Gray.

H. angustifolia, Michx. Erect, usually much branched from a woody perennial base: stems strict, quadrangular, glabrous: leaves linear to oblanceolate-linear, 1 to 5 cm. long, 1 to 5 mm. broad, often hispidulous upon the recurved margins and upon the midrib above: inflorescence cymose, corymbosely or paniculately branched; pedicels slender, erect, 2 to 8 mm. long: flowers dimorphous: calyx-lobes 1 to 1½ mm. long, acute: corolla somewhat funnelform, about 6 mm. long; tube pubescent within; lobes pubescent above: capsule oblong-obovate, about three fourths inferior, the free portion usually a little exceeded by the persistent calyx-lobes; seeds slightly concavo-convex, distinctly scrobiculate. — Fl. i. 85; Gray, Syn. Fl. N. A. i. pt. 2, 26. *Hedyotis stenophylla*, Torr. & Gray, Fl. ii. 41. *Oldenlandia angustifolia*, Gray, Pl. Wright. ii. 68. — Northern Mexico, Texas, northward to Iowa and eastward to Florida. Mexico, Pringle, no. 2260; Texas, Lindheimer, no. 620; Berlandier, nos. 432, 681, 1062, 2413, 2560, etc.; Wright, nos. 239, 240, 1390; E. Hall, no. 285; Palmer, no. 396; Heller, no. 1661. Thurber's specimen, without number, collected at Indianola, seems to be a depauperate form of this species.

Var. filifolia, Gray. Stems profusely branched; leaves linear-filiform: capsule somewhat smaller. — Syn. Fl. N. A. i. pt. 2, 27. *Oldenlandia angustifolia*, Michx., var. *filifolia*, Chapm. Fl. 181. — Texas, between Fredericksburg and San Sabra, Thurber, no. 67; Florida, at

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* Low slender creeping or erect annuals or perennials: flowers usually small on axillary or terminal pedicels or disposed in terminal cymes: capsule obcordate-depressed or oblong, emarginate, one half to three fourths inferior; seeds deep-crateriform, open-crateriform, or oblong, peltate and slightly concave on the hilar surface, usually scrobiculate.

†– Perennial by filiform rootstocks or creeping stems: flowers axillary or on slender terminal pedicels.

H. CÆRULEA, L., Sp. Pl. i. 105, accredited to Mexico by Hemsley (Biol. Centr.-Am. Bot. ii. 30), is essentially a more northern plant, and probably does not extend into Mexico.

H. serpyllacea, C. L. Smith, in herb. A low prostrate or creeping perennial: stems quadrangular, suffrutescent: branches ascending, 3 to 5 cm. high, glabrous: leaves elliptic-ovate, short-petiolate, acute, glabrous on either surface, margin revolute, hispidulous; stipules 1–2-long-setiferous with several shorter glandular setæ: flowers on short axillary pedicels: calyx-divisions lanceolate, acute, somewhat foliaceous, 2 to 4 mm. long; corolla funnelform, about 1 cm. long; lobes above and the throat pubescent: capsule oblong-obovate, 4 mm. long, one half as broad, about three fourths inferior; seeds (6 or more) oblong-rotund or a little oblique, peltate, slightly concavo-convex, prominently scrobiculate. — *Hedyotis serpyllacea*, Schlecht. Linnæa, ix. 599. *Mallastoma Shannoni*, Donnell Smith, Bot. Gaz. xviii. 203. — Jalapa, Schiede; C. L. Smith at Cruz Verde near Jalapa, altitude 2,150 m., no. 1486; Chiapas, Ghiesbreght, no. 814; Guatemala at San Miguel Uspantan, Depart. Quiché, altitude 2,150 m., Heyde and Lux (no. 3176 of Donnell Smith's sets).

†– †– Delicate annuals with minute white flowers and erect or spreading corolla-lobes; seeds open-crateriform, oblong-rotund with a short hilar ridge.

H. croftiæ, Britton & Rusby. A depressed annual: stems 1 to 2 cm. long, hirtellous with a few scattered hairs, especially near the nodes: leaves oblanceolate, 5 to 15 mm. long, glabrous or with a few scattered hirsutish hairs on the midrib above, margins revolute, ciliate: stipules scarious, laciniate-dentate: flowers minute on short axillary pedicels: calyx including the ovary 2 mm. long, hirsute-pubescent; lobes acute: corolla white, 3 mm. long; lobes above short-pubescent: capsule depressed-globose, subdidymous, about one fourth inferior, the free portion short-hirsute-pubescent: seeds open-crateriform, oblong-rotund with a short hilar ridge. — Trans. N. Y. Acad. Sci. vii. 10. — San Diego, Duval Co., Texas, Miss Mary B. Croft, no. 85.

H. parviflora, Holzinger, in litt. A low annual, branching from a single slender root: branches ascending, quadrangular, minutely hispidu-

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CONTRIBUTIONS FROM THE GRAY HERBARIUM OF HARVARD UNIVERSITY, NEW SERIES, No. XI.

By J. M. Greenman.

Presented by B. L. Robinson, 14 April, 1897.

I. — REVISION OF THE MEXICAN AND CENTRAL AMERICAN SPECIES OF HOUSTONIA.

HOUSTONIA, Gronov. (Named in honor of Dr. William Houstoun, born in Scotland, 1695, died in Jamaica, 1733.) — Calyx-tube usually a little compressed; lobes 4, often with one or more minute teeth in each sinus, erect or spreading, persistent, later becoming widely separated. Corolla funnelform or salverform, 4-lobed, glabrous or pilose in the throat; lobes valvate. Stamens 4, inserted in the throat of the corolla; filaments short or elongated; anthers dorsally affixed, oblong or linear. Disk inconspicuous. Ovary 2-celled; style terete, slender, short or elongated; stigmas 2, linear or linear-oblong; ovules in each cell few or many, centrally attached to the median placenta. Capsule $\frac{1}{4}$ to $\frac{3}{4}$ inferior, more or less subglobose, obovate, obovate-oblong, or turbinate; seeds crateriform, acetabuliform, or oblong, peltate and slightly concave on the hilar surface, usually scrobiculate; albumen horny; embryo clavate. — Gronov. in L. Syst. Nat. ed. 1; L. Gen. no. 70; Benth. & Hook. f. Gen. ii. 60; Gray, Syn. Fl. N. A. i. pt. 2, 24; Schumann in Engl. & Prantl, Nat. Pflanzenf. iv. Ab. 4, 27. *Poiretia*, Gmel. Syst. 263. *Panetos*, Raf. Ann. Gen. Sci. Phys. v. 227, vi. 81. *Chamisma*, Raf. in Steud. Nom. ed. 2, i. 776, in syn. — Low slender annuals, herbaceous perennials, or suffruticose plants with reciprocally dimorphous flowers.

§ 1. Euhoustonieæ. Low herbaceous plants often much branched from a woody perennial base: leaves ovate, oblong, linear or subterete, not rigid-setaceous nor acerose-linear: capsule globose, obovate, or oblong-obovate, more or less compressed and usually emarginate: seeds crateriform, acetabuliform, or oblong, peltate and slightly concave on the hilar surface, scrobiculate. — Gray, Proc. Am. Acad. iv. 313.

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Vol. XXXII. No. 16. — June, 1897.

CONTRIBUTIONS FROM THE GRAY HERBARIUM OF HARVARD UNIVERSITY.

New Series. — No. XI.

By J. M. Greenman.

I. Revision of the Mexican and Central American Species of *Houstonia.*

II. Key to the Mexican Species of *Liabum.*

III. Descriptions of New or little known Plants from Mexico.

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Conclusion.

These four cases are the only ones to which I have applied this method of measuring variability. They are, however, taken entirely at random, and are in no wise selected cases. The conclusion to which they all point is that which, on general grounds, seems most likely to be true. This conclusion is, that there is so intimate a causal connection between the characters of individuals and those of the allied groups into which they are combined, that, in proportion as any character is variable in the individuals of one group, it is different in the allied groups.

Finally, I have to express my great indebtedness for assistance, criticism, and suggestion to Dr. Charles B. Davenport and Mr. Frederick H. Safford, both of Harvard University.

Wolfborough, N. H.,
March 5, 1896.

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stant parent species from which *Z. hudsonius*, with its remarkably high coefficient for the ear, has separated. At any rate, in each genus, the characters which mark the species have the highest mean coefficient.

TABLE E.

C. V. OF MEASUREMENTS OF THREE CARNIVORA.

(Measured by the Author.)

	10 Lynx canadensis.	16 Felis domestica.	20 Vulpes fulvus.	Mean of Felis and Lynx.	Mean of 3 Species.
Length of nasal bones	0.050	0.054	0.039	0.052	0.048
Length of frontals	0.038	0.056	0.031	0.047	0.041
Length of snout, incisors to margin of palate	0.039	0.062	0.033	0.050	0.045
Total basal length	0.028	0.054	0.029	0.041	0.037
Length from posterior nares to occipital foramen	0.024	0.058	0.026	0.041	0.036
Length of parietal and occipital bones	0.030	0.046	0.027	0.038	0.034
Length of tooth series	0.044	0.050	0.024	0.047	0.039
Width between canines	0.041	0.055	0.045	0.048	0.047
Width between maxillary bones	0.045	0.040	0.028	0.042	0.038
Width of zygoma	0.049	0.054	0.044	0.051	0.049

Table E gives the *C. V.*'s of ten dimensions of the skulls of the cat, fox, and lynx. A comparison of the skulls of these three forms shows that the representatives of the cat and dog families are very similar, except for the length of the muzzle and the shape of the zygoma. A short muzzle and a wide zygoma are characteristic of all the cats,* and nowhere is the difference between the skulls more marked than in the length of the nasal bones. Examination of Table E shows that it is in just these dimensions — namely, those of the front part of the skull, the zygoma, and especially the nasal bones — that individuals are most variable; while, on the other hand, the "total basal length" and the dimensions of the back part of the skull, which are alike in the two families, give the smallest coefficients of variability.

* Flower ('70), p. 142.

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remaining columns give the relative variability of the several dimensions in individuals of the two species. The numbers at the bottom of the table — "Cases of Agreement" and "Cases of Disagreement" — are found as in Table A. Table C is much less satisfactory than Table A, because the differences in variability between different dimensions are here small, and therefore the relative sizes of the coefficients are more at the mercy of accident. Even here, however, there is a decided preponderance of cases in which individual variation is directly correlated with specific difference.

TABLE D.

C. V. OF FOUR MEASUREMENTS OF TWO GENERA OF RODENTS.
(Based on Miller, '93 and '93[a].)

	Tail.	Hind Foot.	Ear.	Tail and Body.
21 Zapus insignis	0.033	0.027	0.028	0.025
34 Zapus hudsonius	0.054	0.034	0.070	0.043
Mean	0.043	0.030	0.049	0.034
	Tail.	Hind Foot.	Ear.	Body.
105 Sitomys americanus	0.067	0.028	0.050	0.056
90 Sitomys americanus canadensis	0.070	0.031	0.052	0.049
Mean	0.068	0.029	0.051	0.053

Table D is computed from the measurements given with the description of two new species of rodents.* *Zapus insignis* and *Z. hudsonius* are reported to resemble each other closely, but to differ in the length of the ear. *Sitomys americanus* and *S. americanus canadensis* are described as nearly alike except in the length of the tail. Table D shows that, of the four dimensions which are recorded for these species, the mean *C. V.* of the ear is greatest in *Zapus*, and of the tail greatest in *Sitomys*. The *C. V.* in each single species, too, is greatest for the characteristic dimension, except in the case of *Z. insignis*. Possibly *Z. insignis* is the con-

* Miller ('93), pp. 1-8 and 55-70.

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It results, then, from the two lines of numbers at the bottom of Table A, that, in spite of the somewhat inaccurate values of this coefficient, in from two thirds to four fifths of the comparisons, that dimension in any pair which is the more variable among individuals of the same race is likewise the dimension which is the more diverse in the various races. Incidentally it may be noted, too, that the measurements of the face have, in general, the largest coefficients, and thus the high value for personal identification which has long been accorded to photographs of the face alone is justified.

TABLE C.

C. V. OF VARIOUS DIMENSIONS OF SKULLS OF A GENUS (LEPUS) OF RODENTS. (Based on Coues and Allen, '77, pp. 222–226.)

	Mean dimensions of each of 12 Species.	15 Lepus campestris.	13 Lepus palustris.	Mean of the two Species.
Total length	0.121	0.0438	0.0178	0.0308
Greatest width	0.0935	0.0272	0.0239	0.0255
Distance between orbits	0.0825	0.0691	0.0475	0.0583
Nasal bones, length	0.122	0.0732	0.0348	0.0540
Nasal bones, width behind	0.150	0.0684	0.0327	0.0505
Nasal bones, width before	0.178	0.0760	0.0405	0.0582
Upper incisors to molars	0.125	0.0527	0.0280	0.0403
Upper incisors to hinder margin of palate	0.0799	0.0477	0.0238	0.0357
Upper incisors, height	0.146	0.0364	0.0568	0.0466
Upper incisors, width	0.146	0.0502	0.0434	0.0468
Length of upper molars	0.0958	0.0459	0.0393	0.0426
Width between upper molars	0.14	0.0348	0.0452	0.0400
Lower jaw length	0.124	0.0491	0.0240	0.0365
Lower jaw height	0.122	0.0329	0.0174	0.0251
Cases of Agreement		55	59	60
Cases of Disagreement		36	32	31

Table C shows for a genus of rodents what Table A shows for races of mankind. The first column is computed from the means of twelve species and subspecies of the genus Lepus. This gives, therefore, the relative value of these dimensions as specific and subspecific differences. The

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the distribution of *individual* variations. To show the connection between individual variations and racial differences, I take all possible pairs of coefficients in the first nine columns of Table A and compare them with the corresponding pairs in the last column. When, in one of the first nine columns, the member of a pair which is larger is larger in the tenth column also, it counts one in the line at the bottom of Table A marked "Cases of Agreement." When, however, the larger member of a pair in one column is the smaller in the other, it counts one in the line marked "Cases of Disagreement." For example, in the column of Slavs, the *C. V.* of the head length is 0.0314, that of the head breadth is 0.0345, the head breadth being the more variable. In the column of racial differences also, the *C. V.* of the head breadth is greater than that of the head length; therefore this gives in column of Slavs one "Case of Agreement." On the other hand, for the Slavs, the heights of the forehead and of the nose do not agree in relative variability with the means of the twenty races given in the last column; consequently this comparison gives a "Case of Disagreement."

TABLE B.

SHOWING ORDER OF MAGNITUDE OF C. V. OF TABLE A.*

	24 Slavs.	8 Siamese.	12 Japanese.	20 Chinese.	9 Kanakas.	19 Jews.	20 Magyars.	26 Roumanians.	Average.	20 Races.
Head length	17	17	18	17	16	18	17	16	18	18
Head breadth	15	16	16	16	18	13	15	10	17	17
Nose length	5	8	6	3	13	8	1	2	3	3
Nose breadth	12	2	5	4	1	7	5	5	4	5
Nose height	2	1	2	1	9	3	3	3	2	1
Forehead height	1	5	1	2	2	1	2	1	1	2
Under jaw length	8	14	10	7	7	5	7	11	9	14
Mouth breadth	3	3	3	12	14	2	4	4	5	10
Upper face breadth	9	7	4	15	11	14	12	6	11	16
Lower face breadth	18	12	7	14	4	4	6	8.5	7	13
Upper arm length	7	9	9	9	10	9	11	13.5	10	6
Forearm length	11	15	17	11	17	16	9	7	16	15
Middle finger length	4	4	13	13	6	6	16	8.5	6	8
Hand width	10	11	15	10	8	11	14	18	14	4
Upper leg length	16	10	12	5	15	17	8	13.5	13	12
Lower leg length	14	18	8	6	5	12	13	12	12	11
Foot length	13	6	14	18	12	15	18	17	15	9
Foot breadth	6	13	11	8	3	10	10	15	8	7

* I. e. in column "20 Races," head length has C. V. smallest; head breadth, next larger; C. V. of nose height is largest.

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TABLE A.

C. V. of Certain Dimensions in Various Human Races.

(Based on Weisbach, '78, Appendix.)

	24 Slavs.	8 Siamese.	12 Japanese.	20 Chinese.	9 Kanakas.	19 Jews.	20 Magyars.	26 Roumanians.	Average.	Mean dimensions of each of 20 Races.
Head length	0.0314	0.021	0.0205	0.028	0.030	0.0309	0.0293	0.0302	0.0277	0.0244
Head breadth	0.0345	0.024	0.0289	0.287	0.021	0.0363	0.0322	0.0338	0.0298	0.0278
Nose length	0.0532	0.051	0.0504	0.0836	0.041	0.0435	0.17	0.0633	0.0695	0.0949
Nose breadth	0.0446	0.095	0.051	0.064	0.096	0.0447	0.0546	0.0481	0.0613	0.0757
Nose height	0.0683	0.116	0.087	0.106	0.049	0.0575	0.0625	0.0601	0.0758	0.152
Forehead height	0.0721	0.078	0.105	0.087	0.087	0.0941	0.0819	0.095	0.0778	0.104
Under jaw length	0.0459	0.0296	0.0427	0.0567	0.0501	0.0539	0.0435	0.0322	0.0443	0.0481
Mouth breadth	0.0619	0.089	0.0856	0.048	0.0374	0 0619	0.0550	0.0496	0.0611	0 0518
Upper face breadth	0.0457	0.0565	0.0512	0.030	0.0432	0.0361	0.0392	0.0354	0.0422	0.0322
Lower face breadth	0.0288	0.0335	0.047	0.038	0.0678	0.0571	0.0528	0.0344	0.0449	0.0494
Upper arm length	0.0475	0.045	0.043	0.0515	0.0439	0.0423	0.0396	0.0310	0.0430	0.0650
Forearm length	0.0447	0.0259	0.0282	0.0504	0.026	0.0340	0.0412	0.0353	0.0357	0.0385
Middle finger length	0.0537	0.0876	0.0391	0 0429	0 0526	0.0501	0.0297	0.0344	0.0488	0.0595
Hand width	0.0450	0.0344	0.0299	0.0506	0.0493	0.0395	0.0334	0.0236	0.0382	0.0793
Upper leg length	0.0324	0.0391	0.0395	0.0606	0 0347	0.0318	0.0416	0 0310	0.0388	0.0500
Lower leg length	0.0412	0.0205	0.045	0.0591	0.0528	0.0375	0.0350	0.0312	0.0403	0.0504
Foot length	0.0441	0.0620	0.031	0.0238	0.0428	0.0351	0.0267	0.0280	0.0367	0.0592
Foot breadth	0.0499	0.0332	0.041	0.0546	0.0766	0 0414	0.0397	0.0309	0.0447	0 0635
Cases of Agreement	112	115	106	119	105	107	104	90	120	
Cases of Disagreement	41	38	47	34	48	46	49	63	33	

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In practice *C. V.* may be found most readily by separating the given numbers into two groups, as discussed above, and finding the mean of each. The difference between these two means, divided by their sum, is the *C. V.* of the structure under consideration.

Application of the Method of Measuring Variability to the Problem of the Relation between Individual Variations and Specific Differences.

THESIS.

While it is generally agreed that *specific* characters are more subject to striking variations in individuals than are the characters *common to allied species*, it is not clear how far this relation extends. I wish to show that what is true of obvious variations and sports is also true of those minute differences between individuals which only careful measurements can detect; or, in other words, that any measurable quality is, in general, variable in individuals in proportion as it is a distinguishing character of the group to which the individuals belong.

EVIDENCE.

Table A is based on the extensive tables of body measurement of twenty races of men, which are given by Weisbach ('78) in the Appendix to his "Körpermessungen," etc. Each of the numbers of the first eight columns is the *C. V.* of a single dimension of a single race, and the ninth column gives the average for eight races of the *C. V.*'s of each dimension. The values of these *C. V.*'s only approximate to the true values, for the reason that the number of individuals measured is not sufficiently large to eliminate all accidents of age and sex.

An examination of Table A shows that these eighteen dimensions are of nearly the same relative variability in each of the eight races. This fact is well brought out by Table B, in which the largest number of each column of Table A is replaced by 1, the next smaller by 2, and so on up to 18. From Table B it appears that certain dimensions — as, for example, the height of the forehead — are always decidedly variable; and, on the other hand, it appears that other dimensions — such as the length and breadth of the head — are more constant.

The last column of Table A, "Mean of 20 Races," gives the coefficient of variability, not of any individuals, but of the means of each of the twenty races of Weisbach's tables. That is, the *mean value* of a dimension in each race is treated as are the dimensions of individuals in other columns. This column, therefore, shows the distribution of *racial* differences in the same way in which the remainder of the table shows

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In like manner, the sum of all terms less than the mean is

$$\frac{\frac{n\,a}{2} - \frac{n}{2} \ldots . - d - c - b}{\frac{n}{2}}.$$

One half the difference between these is

$$\frac{2\,b + 2\,c + 2\,d \ldots . n}{n}. \qquad \text{(Formula 5.)}$$

But Formula 5 is identical with Formula 4, and is therefore the formula for the average deviation.

Hence the average deviation may be found by separating the numbers into two groups, — one of which shall contain all quantities greater than the mean, the other all those less than the mean, — and taking half the difference between the means of each group.

In practice there will usually be several observed values equal to the mean; these may be distributed to make the two groups of equal size. If the number of observed values is odd, one of these mean values may be neglected.

In order to compare the average deviation of one group of numbers with that of another which has a different mean, it is necessary to reduce the two to a common measure. This is most simply done by dividing each average deviation by the corresponding mean.* It is proposed to call this ratio the *coefficient of variability* and to designate it by the symbol *C. V.*

* The justification for this procedure is found in the following considerations: The relative size of the average deviation of two organs depends very largely upon the relative size of these organs. Where the mean dimension is large, we expect a greater average deviation than where it is small. Thus the average deviation of the stature of adult British males from the mean is about 2 inches. An average deviation of 2 inches in the length of the nose, in any race, would clearly indicate a much greater variability in the nose length than in stature. In comparing the variability of two such diverse measures as stature and nose length, it is better to compare the ratios of the average deviations to the mean dimension. Thus, since the mean stature of adult British males may be taken at 67 inches, variability in stature may be expressed by the ratio $\frac{2}{67} = .02985$. This number indicates that the average deviation from the mean stature is about three one-hundredths of the mean stature; which is clearly more important than to say that it is 2 inches. Moreover, this method of expression has the advantage that it is independent of the unit in which the dimension is measured, whether feet, millimeters, grams, degrees, or ergs. — C. B. Davenport.

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If, then, n be taken sufficiently large,

$$V \propto a\,d. \qquad \text{(Formula 3.)}$$

Even if n is not large, Formula 3 may usually be employed in practice. For in any single investigation n is likely to be constant, — when, as will often be the case, different qualities of the same individuals are to be compared it is necessarily so, — but the introduction of a constant factor will not affect the correctness of the formula.

Practically, $a\,d$ may be found accurately enough without the labor of subtracting each quantity from the mean.

Let

$$a + \frac{n}{2}, \cdots a + d,\ a + c,\ a + b,\ a - b,\ a - c,\ a - d \cdots a - \frac{n}{2}$$

be a series of quantities, n in number, distributed according to the law of probability. The mean is evidently a, and the differences between the several quantities and the mean are

$$\frac{n}{2}, \cdots d,\ c,\ b,\ b,\ c,\ d, \cdots \frac{n}{2}.$$

$$\therefore\ a\,d = \frac{\frac{n}{2} \cdots + d + c + b + b + c + d \cdots + \frac{n}{2}}{n}$$

$$= \frac{2\,b + 2\,c + 2\,d \cdots + \frac{n}{2}}{n}. \qquad \text{(Formula 4.)}$$

Or, again,

$$a + \frac{n}{2}, \cdots a + d,\ a + c,\ a + b,\ a - b.\ a - c,\ a - d, \cdots a - \frac{n}{2},$$

being the series of n measurements as before, the sum of all terms greater than the mean is

$$\left(a + \frac{n}{2}\right) \cdots + (a + d) + (a + c) + (a + b),$$

and of these the mean is

$$\frac{\frac{n\,a}{2} + \frac{n}{2} \cdots + d + c + b}{\frac{n}{2}}.$$

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n individuals, and let d_1, $d_2 \ldots d_n$ represent the difference between each number of the series and the mean of all.

Then

$$\frac{0.8453\ (d_1 + d_2 \ldots d_n)}{\sqrt{n\ (n-1)}},$$

which is the common working formula for probable error,* is a measure of the variability of the given quality in this particular group.

Or, in symbols,

$$V \propto \frac{0.8453\ \Sigma d}{\sqrt{n\ (n-1)}};$$

where V stands for variability, $\Sigma d = d_1 + d_2 \ldots d_n$, and $\propto$ may be read "is measured by." This is, appproximately, Galton's Q.

Obviously,

$$V \propto \frac{\Sigma d}{\sqrt{n\ (n-1)}}. \qquad \text{(Formula 1.)}$$

In Formula 1,

$$\sqrt{n\ (n-1)} = \sqrt{n^2 - n} = \sqrt{n^2\left(1 - \frac{1}{n}\right)} = n\sqrt{1 - \frac{1}{n}}.$$

$$\therefore\ V \propto \frac{\Sigma d}{n} \times \frac{1}{\sqrt{1 - \frac{1}{n}}}.$$

Consider the expression, $\frac{\Sigma d}{n}$.

Here Σd is the sum of all differences between single numbers of the series and the mean of the series. Since these are n in number, $\frac{\Sigma d}{n}$ is the *average deviation* of single values from the mean value.

Let $a\,d$ be the symbol for this average deviation. Then,

$$V \propto a\,d \frac{1}{\sqrt{1 - \frac{1}{n}}}. \qquad \text{(Formula 2.)}$$

Suppose, however, that the number of cases measured is large; that is to say, that n is made indefinitely large. As n approaches infinity, $\frac{1}{n}$ approaches 0, and consequently $\frac{1}{\sqrt{1 - \frac{1}{n}}}$ approaches 1.

* See any text-book treating of such subjects; for example, Merriman ('84), p. 93.

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CONTRIBUTIONS FROM THE ZOÖLOGICAL LABORATORY OF THE MUSEUM OF COMPARATIVE ZOÖLOGY AT HARVARD COLLEGE, E. L. MARK, DIRECTOR, NO. LXXIX.

A MEASURE OF VARIABILITY, AND THE RELATION OF INDIVIDUAL VARIATIONS TO SPECIFIC DIFFERENCES.

By Edwin Tenney Brewster.

Presented by E. L. Mark, April 14, 1897.

Problem.

This paper, prepared under the supervision of Dr. C. B. Davenport, deals with an inquiry into the relation between those small variations which distinguish individuals of the same group, and those larger differences which separate species and genera.

For the prosecution of such an inquiry, it is, first of all, necessary to devise a method of measuring variability. Quetelet ('46), Stieda ('82), Galton ('91), and Weldon ('93) have shown that variations in organisms follow the well known laws of the distribution of error. Thus the ordinary methods of treating problems in error of observation may be made to furnish a measure of variability; it is upon these methods that the methods of this paper are based.

Method.

Any measurable quality of an object has a value, which is expressible by a number. A series of such numbers, expressing the varying value of a quality throughout a group of similar objects, will have a mean, about which the quantities are arranged in accordance with the law of distribution of error. Such a series is, for the present purpose, essentially like a series of slightly erroneous observations of a single quantity distributed about the true value. What, therefore, would be the probable error in the latter case, is a measure of variability in the former.

Suppose such a series of numbers obtained by measuring some single quality in each individual of a natural group of organisms. Let there be

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than one of two inches in length. In popular language, it can be maintained that a discharge of lightning a mile long encounters no more resistance than one of a foot in length. Ohm's law does not hold for electrical discharges in air and rarefied gases. It is well known that a voltaic arc can be started in a vacuum. My experiments lead me to believe that in every case the arc is started by a spark which breaks down the medium, and the arc follows. I am led to believe that electrical oscillations are of the nature of voltaic arcs, and that the discharges in Crookes tubes are voltaic arcs. I am thus forced to the conclusion that under high electrical stress the ether breaks down and becomes a good conductor.

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ably does so by blowing out the voltaic arc which tends to form. It may be that the electrodynamic repulsion compels the oscillations of the spark not to follow, so to speak, the voltaic arc and its current of heated air. It seems as if the oscillations of the spark were true voltaic arcs, and that the electrodynamic repulsion blows these out. There are, however, just as many oscillations in the magnetic field as outside of it. The field exerts no influence on the number of oscillations, or on their apparent duration. The loud report which is produced when a spark is formed in a magnetic field, notably when the primary circuit of an ordinary Ruhmkorf coil is broken in a strong magnetic field, may indicate a sudden stress in the medium; in the case of the Crookes tube, the highly rarefied medium within it would effectually prevent our hearing a similar report.

In order to see if the radiations from a Crookes tube emitting Röntgen rays could produce any effect upon the primary spark of the Thomson Tesler transformer, I produced it near a Crookes tube, and examined it by the method of damping. No change in resistance could be perceived, and no effect was observed upon the length of the spark produced by the secondary of such a transformer. In the next place, I resolved to determine whether differences in the materials of the spark gap made any appreciable difference in the resistances observed in disruptive discharges. I accordingly employed terminals of platinum, iron, aluminium, brass, cadmium, zinc, and carbon. No difference arising from difference of metals could be noticed. These experiments confirm the results obtained by Rhigi * and by De La Rue and Hugo Müller.†

Moreover, no difference of resistance between spheres, between pointed terminals, or between a point and a plane, could be perceived. With powerful discharges such differences disappear. The employment of a powerful storage battery together with a Planté rheostatic machine shows conclusively that the discharge in a Crookes tube, when on the point of emitting the Röntgen rays most intensely, is an oscillatory one, and that such discharge encounters a resistance less than five ohms. An estimate of the great amount of energy thus developed in an exceedingly small interval of time can be obtained if we suppose that Ohm's law holds for individual oscillations. This reservation is an important one, for the investigations I have described in this paper show that a discharge of six inches in length encounters no more resistance during its oscillations

* Nuovo Cimento, [2.], Vol. XVI. p. 97, 1876.
† Phil. Trans., Vol. CLXIX. Pt. 1, p. 93, 1878.

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high voltages which can be obtained by the use of the Planté machine. A Geissler tube containing hydrogen at 1 mm. pressure was placed between the terminals of the Planté machine together with a spark gap. This tube would give only four half oscillations with ten thousand volts and gave twenty half oscillations with approximately 300,000 volts, the electrical circuits being the same in the two cases.

I next placed the additional spark gap in the flame of a Bunsen burner. It is well known that the spark length can be greatly increased in an atmosphere of heated air. On photographing a spark produced in the same circuit, the resistance appeared to be slightly increased by the heated air; doubling the length of the spark, however, made no change in the resistance that was encountered in the heated medium. The phenomenon was very analogous to that observed in the receiver exhausted to 100 cm. It is well known that lightning follows currents of heated air, striking into barn doors from which arise hot air currents from hay, and passing into chimneys from which issue heated air. The striking fact is presented that the medium breaks down more easily when it is heated; but it offers during the oscillations of the lightning somewhat more resistance than cold air.

I was interested to discover whether heating the air in which the spark in the primary of the Thomson Tesla transformer is produced would have any marked effect on the high tension spark of the secondary of such a transformer. It was immediately evident that such heating of the air was detrimental. The high tension sparks immediately ceased to jump at the extreme sparking distance of the terminals. Following this train of thought, I next placed a spark gap of the primary of the above mentioned transformer between the poles of a powerful magnet, giving a field of certainly ten thousand lines to the centimeter. It is well known that when such a field is excited the primary spark appears to be blown out with a loud report, and a great increase of length of spark is obtained in the secondary of the transformer. Applying the method of estimation of resistance by damping to an additional spark gap which was placed in this magnetic field, I found no difference in resistance offered to the spark, whether the magnetic field was excited or not, or whether the spark jumped across the direction of the magnetic lines or in the same direction. Is it possible that, the ether being already under a magnetic stress, the addition of a powerful electrostatic stress serves suddenly to break down the ether? It is well known that a blast of air imitates the action of a magnetic field, and produces also a great increase of spark in the secondary circuit of a Thomson Tesla transformer. It prob-

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in length and when it was one inch in length. I found, moreover, on increasing the electromotive force, that the resistance of the sparks in air decreased. By quickly drawing apart the terminals of the large storage battery of ten thousand cells, a flaming arc discharge can be produced in air of nearly three feet in length. Rhigi has shown also that sparks from an electrical machine or Leyden jars can be greatly increased in air by quickly drawing apart the spark terminals. We thus see that very little resistance is encountered by more than quadrupling the length of discharge.

I next placed the additional spark gap in a receiver connected with an ordinary air pump, and studied the resistance offered by rarefied air at the point when long ribbon-like white disruptive discharges can be obtained. This point is about 100 cm. pressure in the receiver. The resistance of such discharges of about six inches in length in a receiver containing air at this pressure is two or three ohms more than sparks one quarter of an inch in air. The latter offer a resistance of from two to three ohms. On measuring by the damping method the resistance of sparks of different lengths in the receiver at this pressure, no difference in resistance could be perceived between a spark of six inches in length and one of three inches in length. The method would have detected a difference of half an ohm.

The additional spark gap was next placed in a chamber of air which was compressed to four atmospheres. This amount of compression made no difference in the resistance to the disruptive discharges. It would be interesting to push this research to the amount of compression reached by Professor Dewar in the case of liquid oxygen. He has obtained a dielectric constant for liquid oxygen of 1.45. When this dielectric, however, is broken down by a disruptive spark, I am inclined to believe that it would show little more resistance than air under the same circumstances.

The additional spark gap was next placed in hydrogen gas generated at atmospheric pressure by electrolysis. No appreciable difference at this pressure was noticed between the resistance offered by this gas and air at the same pressure. The length of spark which could be obtained with a given voltage was somewhat more in hydrogen than in air. It has been shown by Professor T. W. Richards and myself that the resistance of gases at low pressures diminishes with the increase of electromotive force.* I was interested to test this question by the employment of the

* Am. Journal of Science, April, 1897.

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force, therefore, employed to charge the jars, the less resistance would occur at the brushes where the change from multiple to series occurred, and therefore the less the loss of energy due to Joule's heat. I therefore investigated the length of spark obtained from the Planté machine by continuing the curves plotted by De La Rue and Müller,* and found that, starting with 10,500 volts, and increasing the Leyden jars progressively, the length of sparks plotted as ordinates and the rise in voltage (NV) gave a straight line which was an extension of those obtained by them. Furthermore, as will be shown later, differences between points and planes, and points and paraboliform surfaces disappeared with high voltages. In order to ascertain if the discharges through Crookes tubes when the Röntgen rays were apparently produced most strongly were oscillatory, I first placed a Geissler tube in the circuit with the Crookes tube, and carefully observed the appearances at the two electrodes of the Geissler tube. The electrodes were quite alike in appearance, and indicated an oscillatory discharge. I then replaced the Geissler tube by a small spark gap, and photographed it in the rapidly revolving mirror.

The photograph showed ten clearly defined oscillations, with a period of about one ten-millionth of a second, with the Crookes tube and the circuit I employed. Furthermore, applying the method of estimating resistances by the method of damping, I found that the resistance of the rarefied medium was less than five ohms. The energy therefore at the moment of the emission of the Röntgen rays was not far from 3,000,000 horse power acting for one millionth of a second. The Crookes tube which I employed was of the focus tube pattern (King's College, London). I also employed a Crookes tube with an aluminium mirror of about two centimeters' focus. The resistance of this tube to the discharge was approximately the same as that in which the mirror had a focal length of about five centimeters. There seemed to be no advantage in shortening the distance between the anode and the kathode in a Crookes tube. Struck by the fact that the distance between the electrodes did not appear to make any appreciable difference in the resistance offered by the Crookes tube to oscillating currents, I replaced the tube by a spark gap in air of six inches in length, and photographed the spark in another gap in air in the same circuit. This latter gap was 6 mm. in length. The photographs showed on the average the same number of oscillations, both when the additional spark gap was six inches

* Proc. Roy. Soc., Vol. XXXVI. p. 151, 1883-84.

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tion, and the wires from the storage battery are led to a switch board in this room. A connecting room contains a Rowland grating.

With the facilities at my command, I set to work to investigate the conditions which seem to be necessary to produce the Röntgen rays. I have said that my previous experience in studying oscillatory discharges had led me to select cadmium for the material of the terminals of a spark gap. The light is highly actinic and with not too strong discharges, and with sharply pointed terminals well defined images of even minute evidences of oscillations can be obtained. I have also experimented with various developers, and finally adopted Rodinol. This developer works with great intensity, and quickly brings out the latent images. The study of rapid electrical oscillations enables one to estimate with considerable accuracy the merits of different developers for instantaneous photography. With a definite electrical circuit consisting of a known capacity (Leyden jar) and a known self-induction, together with constant rate of speed of the revolving mirror, one can obtain the time of exposure; and the number of oscillations brought out by the various developers is a guide to their relative values.

Having at my command a battery giving a voltage of twenty thousand, with an internal resistance of only one quarter of an ohm per cell, and therefore capable of giving a very powerful current, I first studied the behavior of Crookes tubes, which were directly connected to the terminals of this battery. I speedily discovered that no Röntgen rays could be obtained with a voltage of twenty thousand. On strongly heating the Crookes tubes they were filled with a pale white light, which showed very faint bands in the green when examined by a spectroscope. After a short interval, the entire strength of the battery appeared to be manifested in the tubes, the electrodes became red-hot, the medium apparently broke down, and offered little resistance to the battery current. This white discharge showed, even at its culminating point, no Röntgen rays, and appeared to be of the nature of a voltaic arc discharge. I then employed the Planté rheostatic machine. I found that at least one hundred thousand volts were necessary to produce the Röntgen rays, and that they were produced more intensely as I increased the voltage, — certainly to the point of five hundred thousand volts. In order to ascertain how great a loss occurred in this machine on discharging in series, I investigated the length of spark obtained by varying the number of Leyden jars in this machine. Experiments to be described later in this paper had shown me that increase of electromotive force diminished the resistance offered to a spark in air. The higher the electromotive

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of these is placed in a gas or under the conditions which are to be examined, while the other is protographed according to Feddersen's method by a revolving mirror. A previous study of the behavior of various electrodes had led me to select cadmium for the terminals of the spark gap which are examined by the revolving mirror. The light from cadmium is very actinic; and with carefully pointed terminals shielded from the currents of air produced by the revolving mirror, very sharp photographs of electrical oscillations can be obtained. The resistance of a spark in air or in rarefied media can be estimated by this method to one half an ohm.

The revolving mirror which I employed was the one I have used in previous researches.* It is a glass concave mirror of ten feet focal length, silvered on its concave surface, and corrected for the use to which it was put. The improvements in electric motors and storage batteries enables one to obtain great steadiness of rotation. The accompanying figure represents the revolving mirror, together with the electric motor and the chronograph, and the diagram explains the parts. Figure 4 is the apparatus in elevation, and Figure 5 in plan. *M* represents the mirror, *E* the motor, *C* the chronograph, *S* the stylus, *K* the cutting tool for obtaining electrical contact at the instant the mirror reaches a definite angle in its revolution. This cutting tool passes through a strip of type metal, *T*. This strip is adjusted up and down by the screw *O*, and is adjusted in a direction at right angles by the spring bolt *P*. The catch *R* releases *P*, at any desired moment, by means of a tension on a string connected to it. The stylus *S* is drawn along guides by a string which is connected through clockwork to a weight, *W*. A fan, *F*, serves to control the movement of *S*. The stylus is also released by a catch which can be tripped at any moment by the operator.

The camera consisted of a box ten feet long, made of a trussed frame covered with black cloth. This camera is shown in plan and elevation in Figure 6. *M* is the revolving mirror, *C* the camera, *S* the spark gap, *P* a partition which extends one quarter way through the interior of the camera to shield the photographic plate at *N* from the direct light from the spark gap *S*. The photographic room in which this camera is placed was about twenty-five feet square, and was provided with shutters of orange fabric. In one corner of the room is the developing closet. The same room contains a mercury pump for exhaus-

* Phil Mag., 1894; Am. Journal of Science, 1894; Velocity of Electric Waves, Am. Journal of Science, 1895.

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two distilled water resistances which enable one to control the strength of current of the battery. The cells are charged in multiple with only twenty in each branch of the divided circuit; and they are always left on the multiple circuit when not in use. The resistance of each cell is about one fourth of an ohm, and the electromotive force about 2.1 volts. A study of the voltage of each case by means of a voltmeter showed that the voltage could be closely estimated by knowing the number of cells.

The Planté rheostatic machine, by means of which one can rise from the voltage of the battery (20,000) to 500,000 volts,* is a practical modification of that described by its author. Instead of mica plates, the mechanician of the Laboratory, Mr. Thompson, selected glass plates 8×10 inches, one tenth of an inch thick: these were coated with tinfoil to within one inch of the edges of the plate. At first it seemed doubtful whether glass of this thickness would stand the high voltages to which it would be subjected. Preliminary experiments, however, showed that this thickness of glass would stand a steady stress of twenty thousand volts, — although it would break down under much less voltage arising from alternating stresses. I have employed thirty of such glass condensers or Franklin plates, which are charged in multiple by the battery of from five thousand to ten thousand cells: that is, all the coatings of one side of the plates are connected with the — pole of the battery, and the coatings of the other side with the + pole of the battery. The change from multiple to series is accomplished by a series of brushes which are arranged on two vulcanite rods. These brushes are connected with the coatings of the glass plates. A revolving drum provided with pins and connecting wires is driven by an electric motor, and serves rapidly to change the connection of the condensers from multiple to series.

Starting from the point reached by De La Rue and Müller, about 15,000 volts, the Planté rheostatic machine shows that the length of spark is closely proportional to the electromotive force. On plotting lengths of sparks as ordinates, and NV as abscissas, N being number of Franklin Plates, a straight line is obtained.

The method I have employed for studying the energy conditions in Crookes tubes, and in the production of electrical discharges in general, may be termed the damping of an additional spark method, or the comparison of resistances by the estimation of the damping of electrical oscillations.† The electrical circuit is provided with two spark gaps. One

* Comptes Rendus, Tom. LXXXV. p. 794, Oct. 29, 1877.

† Damping of Electric Oscillations, These Proceedings, Vol. XXVI.

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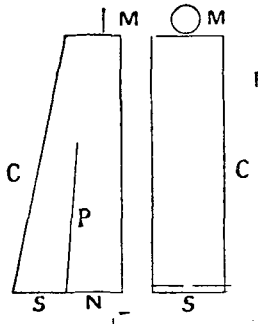

Fig 6

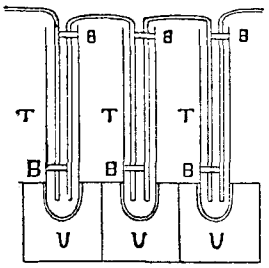

Fig 1

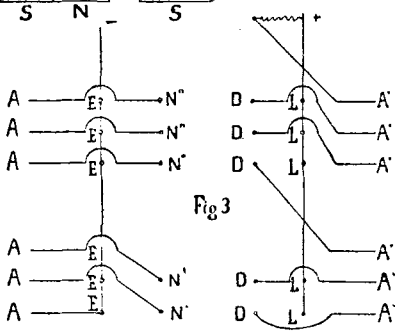

Fig 3

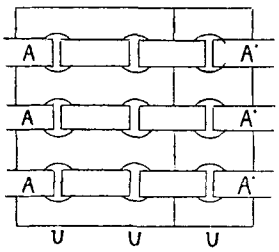

Fig 2

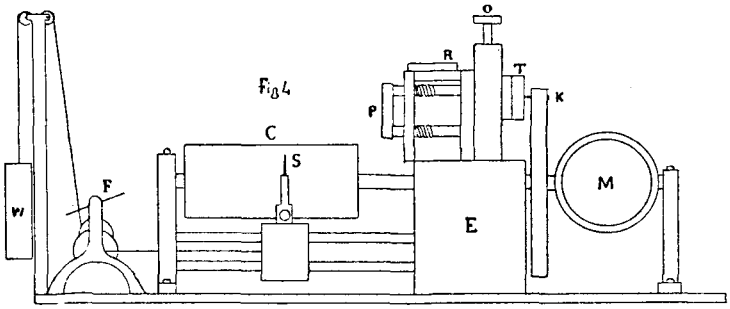

Fig 4

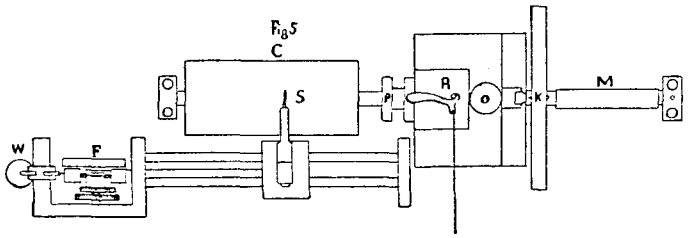

Fig 5

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the terminals of the cells are made of thick lead wire, which are led through wooden supports far from any possibility of corrosion where they connect to the copper wires of the main circuits. The unit of the battery consists of three test tubes, mounted in holes bored in blocks of wood $5 \times 5 \times 15$ cm. (*U*, Figs. 1 and 2). These blocks of wood are boiled in paraffine, and the tubes are held upright by means of paraffine, which is poured into the holes in which the tubes are inserted, these holes being made slightly larger than the tubes. On solidification the tubes are held upright. There are twenty of such blocks on each shelf of one upright case, thus making sixty cells to a shelf; and there are seven shelves to a case, making four hundred and twenty cells to a case. On the back of such cases are arranged knife-edge switches, which enable me to arrange the cells in multiple or in series, — to employ one shelf or the entire number. At the extremity of each row of six cases is a switch board with similar switches, which enable me to use one case or any combination of the entire number of six cases. These switch boards consist of dry whitewood, the insulation of which has been found to answer perfectly. Since the practical success of such a large battery depends upon the ease with which the cells can be charged in multiple and discharged in series, I have represented the scheme of connections of two shelves, sixty cells on each case. The remaining cells on successive shelves of each case are connected in a similar manner. *A* and *A'* (Fig. 3) represent the terminals of each line of twenty cells. Their lead terminals are led to the back of the case, where there are switches which have pivots at the points *E* and *D*. These switches, revolving about the pivots *E* and *D*, connect the terminals of the cells to a wire running through the pivots *E*, and through the points *L*; in which case the cells are in multiple. If, however, the points *N'* and *N''* are thrown out by revolving the switches about *E*, and the points *L* of the switches are connected to *N'* and *N''*, the cells are thrown into series. This operation can be quickly accomplished, the points *N'* and the points *N''* moving together, and also the points *L* moving together about the pivots *D*. In arrangement for series, therefore, the current goes from *D* to *N'*, then to *A*, then through the row of twenty cells to *A'*, thence to *D*, to *N'*, and to *A*, again to *A'*, and then to the next row of switches corresponding to the next shelf, and so on.

A similar plan of switch boards has been erected for each half of the entire battery, consisting of five thousand cells, in order that one half of the battery may be used, or the entire number of cells. At the experimental table to which the terminals of the battery are led there are

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THE ENERGY CONDITIONS NECESSARY TO PRODUCE THE RÖNTGEN RAYS.

By John Trowbridge.

Presented March 10, 1897.

This paper is a preliminary study of the conditions which exist in highly rarefied media under discharges of electricity, conducted by means of the large storage battery of the Jefferson Physical Laboratory.

The value of a large storage battery for the study of the discharge of electricity through gases has long been recognized, and such batteries of 1,800 to 2,000 cells have been constructed by Zehnder, by Quincke, and others. Quincke devotes a large portion of a recent article * to a description of the details of construction of such a battery of 1,200 cells. The battery of the Jefferson Physical Laboratory consists of 10,000 cells, and it is of such practical construction that I believe a detailed account of it will be of advantage to those contemplating the installation of a similar one. When I was considering the cost of such a battery, Professor B. O. Peirce, my colleague, expressed the opinion that dry wood would serve perfectly well for insulating material; and the mechanician of the Laboratory, Mr. G. W. Thompson, coinciding in this opinion and deprecating the use of vulcanite or any of the forms of insulators in the market, on account of the loss of insulation due to surface action, I decided to adopt wood for the supports of the cells of the battery.

There are 10,000 cells, each one consisting of a test tube $5\frac{1}{2}$ inches long and 25 mm. diameter, shown in elevation and plan in Figure 1 and Figure 2. The plates of the cell are strips of lead 1 mm. thick, 12 mm. broad, which have been run through a peculiar mill to give them a corrugated surface. The strips do not reach to the bottom of the tubes, in order to avoid short circuiting due to a possible falling off of the peroxide of lead. They are separated by rubber bands, *B*, and

* Annalen der Physik und Chemie, No. II. p. 417, 1896.

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Proceedings of the American Academy of Arts and Sciences.

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THE ENERGY CONDITIONS NECESSARY TO PRODUCE THE RÖNTGEN RAYS.

By John Trowbridge.

Investigations on Light and Heat, made and published wholly or in part with Appropriation from the Rumford Fund.

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reached a great height; but in presenting a summary of the results to the French Academy,* E. Mascart, the director of the French Meteorological Office, remarks that there is reason to hope that this international co-operation will contribute valuable data to our knowledge of the variations of temperature and wind in the upper atmosphere.

As the American representative of the International Aeronautical Committee, the writer hopes that in this country a similar exploration of the high atmosphere with registration balloons will be attempted, and he is now preparing an estimate of the cost to submit to the trustee of the Hodgkins Fund. Since it should supplement his own researches with kites which are described first in this paper, he has taken the occasion to bring the subject of free registration balloons to the attention of the Academy.

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* Comptes Rendus, Vol. CXXIII. No. 22, pp. 918, 961.

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and a free balloon, both equipped with self-recording instruments. The latter, called the *Cirrus*, of 8,830 cubic feet capacity, when inflated with coal-gas had a lifting force of about 290 pounds, besides its envelope weighing 93 pounds, and the meteorological apparatus weighing nearly 6 pounds. This is more complicated than the French instruments, since the registration is photographic, and a continuous ventilation of the alcohol thermometer in Assmann's aspiration apparatus is effected by allowing a weight to drive the aspirator. Even with these precautions, the temperatures are probably too high, and the registration is often defective. There have been seven flights of the *Cirrus*, one of the highest occurring in September, 1894, when the unprecedentedly low barometric pressure of about two inches of mercury was recorded, giving a computed height of 60,500 feet. The lowest temperature, which was registered at a somewhat less altitude, was not below —88° Fahrenheit, giving rise to the supposition that the thermometer was heated by insolation. Hence the average decrease of temperature appears to have been but 1° in 409 feet. This balloon rose from Berlin with the great velocity of about 30 feet per second, and travelled 560 miles in an east-northeast direction at a velocity of 83 miles per hour.

For some time past negotiations have been in progress between the French and the Germans for simultaneous ascents of unmanned balloons at night, using identical instruments, whereby the errors due to insolation, and the discrepancies which might be attributed to different instruments, would be avoided. By this co-operation the simultaneous conditions of the upper air over a wide extent of country can be ascertained, just as these conditions near the earth's surface are daily obtained at the meteorological stations in the different countries. The desired result was brought about by the International Meteorological Conference which met last September in Paris. Resolutions were adopted favoring scientific ascents with manned balloons, as well as simultaneous flights of unmanned registration balloons in the different countries. The successful use of kites at Blue Hill to lift self-recording instruments over a mile into the air, led to expressed desire that similar experiments should be tried elsewhere. An international committee was appointed to carry out these resolutions, consisting of Messrs. de Fonvielle and Hermite for France; Assmann, Erk, and Hergesell for Germany; Pomortzeff for Russia; and the writer for the United States. In accordance with the first named resolutions, a flight of four manned and four registration balloons occurred in France, Germany, and Russia on the night of November 13–14 last. Owing to hurried preparations, only the registration balloon liberated from Paris

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above the earth, where the pressure is about one ninth that at the earth, the balloon must lift itself from the ground when one ninth filled with gas. Therefore a relatively large balloon is required, and its initial velocity of ascent is great, because it is found advantageous to fill the gas-bag completely. The greatest difficulty has been to protect the thermometers from insolation, and to insure records being made, notwithstanding the great cold to which the instruments are exposed.

The first systematic experiments of the kind were made in Paris, in 1893, by G. Hermite, who was later associated with G. Besançon. There have been six high ascents from Paris of the three balloons called *L'Aérophile*. The second one of the name had an envelope of gold-beaters' skin, with a capacity of 6,360 cubic feet, which when nearly filled with coal-gas gave an initial lifting power of 235 pounds, in excess of its own weight of 49 pounds, and the instruments and screens, which weighed 12 pounds. With this balloon, in October, 1895, at an approximate height of 46,000 feet, a temperature of —94° Fahrenheit was recorded, which is the lowest noted in a balloon, and probably the lowest natural temperature observed on the earth. The average decrease of temperature was 1° Fahrenheit for 320 feet of height. The instruments used are of the well known Richard type, and have been tested in a chamber whose pressure and temperature are lowered to the limits which it is expected may be reached by the balloon. They are placed below the balloon in a wicker tube six feet high, lined with silvered paper to ward off the sun's rays. It is believed by Hermite, that during the rapid ascent of the balloon the draught of air through the tube is sufficient to neutralize the heating of the enclosed air by the sun. It is admitted that when equilibrium is nearly reached this may not be true, and that the temperature recorded near the highest point may be too high. To avoid freezing of the ink the registration is now made on smoked paper, and to protect the instrument from shocks it is hung by springs in a closed basket, which is itself suspended in the tube already mentioned. An apparatus for obtaining samples of air at high altitudes has been carried by the balloon, but as yet without success, owing to difficulties in hermetically closing the receiver after the air has entered, since mechanically closing the inlet tube and sealing it by heat generated chemically have each proved ineffectual at great heights.

By means of a grant from the German Emperor to the Deutsche Verein zur Förderung der Luftschiffahrt, R. Assmann, A. Berson, and others in Berlin, have been able to carry on an extensive series of meteorological investigations with manned balloons, and also with a captive

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in fair weather the days are damper than the nights. "Cold and warm waves" commence in the upper air, as is proved by the temperature decreasing faster than normal, or even increasing abruptly, with altitude before the fall or rise of temperature commences at the earth's surface. Several ascents through clouds have shown the air above them to be usually warmer and drier than the air below. Kites furnish a ready and accurate method of measuring the heights of certain low and uniform clouds, which could not easily be measured otherwise in the daytime. It is interesting to note that this method was used by Espy, about 1840, to verify his calculations of the height at which condensation begins.* Changes of wind direction in the different air strata are determined from the azimuths of the kites, and this change sometimes amounts to 180°. The wind velocity usually increases with altitude, and vertical currents commonly prevail near cumulus clouds. During high flights the wire is strongly charged with electricity, but no measurements of its kind or potential have lately been attempted.

The writer is glad to acknowledge his indebtedness to his assistants, Messrs. Clayton and Fergusson, who have devised and constructed improved kites and apparatus, and during his absence have taken entire charge of the work. To them and to another assistant, Mr. Sweetland, is largely due the success which has been attained in this novel branch of research. For still higher ascents there will be required a steam engine to operate the windlass, and a meteorograph with a lower pressure scale. With these appliances, for whose purchase a grant has been asked from the Hodgkins Fund of the Smithsonian Institution, it is probable that records can be obtained three miles above Blue Hill, and possibly higher.

To reach much higher altitudes, unmanned free balloons, or "ballons sondes" as they are called, have been considerably used both in France and Germany. These balloons, which carry self-recording apparatus, rise until equilibrium is attained in the rarefied air. When they lose their buoyancy and fall to the earth, most of them have been recovered, with the instruments and records uninjured, by the senders, who have been notified by the finder of the place of descent, which is often at a great distance from the starting point. The altitudes are calculated from the barometric pressure, according to Laplace's formula, but the impossibility of knowing the mean temperature of the whole mass of air makes the determination inexact. Theoretically, in order to ascend ten miles

* Philosophy of Storms, 1841, p. 75.

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The details of the work, as now carried on at Blue Hill, are as follows. The kites, which have no tails, are of Eddy's Malay, or of Hargrave's cellular types, the former presenting a convex surface to the wind, and the latter two pair of superposed planes, each pair being connected by side planes. In addition to the two leading kites, others are attached by independent cords to various points of the line, which is a steel music wire, 0.033 inch in diameter, having a tensile strength of three hundred pounds, and weighing fifteen pounds per mile. The meteorographs are composed mostly of aluminium and weigh less than three pounds each, the one constructed by J. Richard, of Paris, recording on a single clock cylinder atmospheric pressure, air temperature, and relative humidity, while that made by Mr. Fergusson similarly records wind velocity and air temperature. One of these instruments is hung to the wire between two kites, in order to insure its safety in case of breakage of the wire or of one kite, or the failure of the wind to support the latter. The wire is coiled upon the drum of a windlass, which may be turned by two men, and a measuring device registers the amount of wire uncoiled, while the angular elevation of the meteorograph, when not hidden by clouds, is observed from time to time with a surveyor's transit at the windlass or at the ends of a base line. From these data, or from the barometric record, the altitude of the meteorograph is calculated. Kites may be flown in all kinds of weather, whenever the wind's velocity is between fourteen and thirty-five miles an hour; and since on Blue Hill the average velocity is more than eighteen miles an hour, days are frequent when flights are possible.

Probably the greatest elevation yet attained by kites, and certainly the highest level to which kites have lifted a meteorograph, is 8,740 feet above Blue Hill. This was accomplished, October 8, 1896, by the aid of nine kites, having a total area of 170 square feet, which gave a maximum pull at the ground of about 100 pounds.* The meteorograph remained during several hours higher than a mile, and good records of the indications of the barometer, thermometer, and hygrometer were brought down. More than one hundred records of atmospheric pressure, temperature, and relative humidity of the air, or wind velocity, at intermediate heights up to the extreme altitude just stated, have been obtained, and they are being discussed for publication with the Blue Hill observations for 1896, in the "Annals of the Astronomical Observatory of Harvard College." A few general conclusions may be mentioned. At the height of about a mile the diurnal changes of temperature in the free air nearly disappear, although

* Science, Nov. 13, 1896, p. 718.

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for meteorological researches, except during calms which sometimes occur at the earth's surface, but rarely extend aloft.

There remain kites and unmanned balloons, both recording graphically and continuously the chief meteorological conditions, and these it is my intention to describe in this paper. The recent development of the kite for meteorological purposes has taken place in the United States, while the use of the automatic balloon for obtaining data at very great altitudes has hitherto been confined to Europe.

Kites appear to have been first applied in meteorology by Alexander Wilson, of Glasgow, who in 1749 raised thermometers attached to the kites into the clouds.* Three years later, Franklin performed in Philadelphia his celebrated experiment of collecting the electricity of the thunder-cloud by means of a kite.† Although kites have served a variety of purposes, their first systematic use in meteorology was probably in England, between 1883 and 1885, when E. D. Archibald made differential measurements of wind velocity by anemometers raised by kites fifteen hundred feet.‡ In 1885, A. McAdie repeated Franklin's kite experiment on Blue Hill, using an electrometer,§ and in 1891 and 1892 made simultaneous measurements of electrical potential at the base of Blue Hill, on the hill, and several hundred feet above it with kites as collectors.‖ The invention of light-weight self-recording instruments made it possible to obtain graphic records in the air by means of kites, and after W. A. Eddy had introduced tailless kites into this country, and had attached a minimum thermometer in 1891,¶ a thermograph reconstructed of lighter materials by S. P. Fergusson, of the Blue Hill Observatory, was raised on August 4, 1894, 1430 feet above the hill.** It was no doubt the first instrument, recording continuously and graphically, to be lifted by kites, and it permitted simultaneous observations to be obtained in the free air and near the ground. This method of studying the meteorological conditions of the free air has ever since been in regular use at the Blue Hill Observatory; but notwithstanding the general interest which has recently been aroused in kites, it is not known by the writer that meteorographs have elsewhere been raised by them.

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* Trans. Roy. Soc. of Edinburgh, Vol. X. Part II., pp. 284–286.
† Sparks's Works of Benjamin Franklin, Vol. V. p. 295.
‡ Nature. Vol. XXXI.
§ These Proceedings, Vol. XXI. pp. 129–134.
‖ Annals Astr. Obs. Harv. Col., Vol. XL. Parts I. and II., Appendices A and C.
¶ Am. Met. Journal, Vol. VIII. pp. 122–125.
** Ibid., Vol. XI. pp. 297–303.

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ON OBTAINING METEOROLOGICAL RECORDS IN THE UPPER AIR BY MEANS OF KITES AND BALLOONS.

By A. Lawrence Rotch.

Presented January 13, 1897.

A knowledge of the physical conditions which prevail up to the highest cloud levels, five to nine miles above the earth, is of great importance to meteorologists, who until recently have been studying principally the conditions existing near the floor of the aerial ocean, and from that standpoint have endeavored to formulate the laws which control the pressure, temperature, humidity, and currents in the great volume of air above them. Continued and systematic observations on mountains in different parts of the world latterly have contributed much to our knowledge of the approximate conditions of the atmosphere, under various circumstances, up to a height of more than three miles above sea level, but the mass and surface of the mountain, even when this is an isolated peak, influence very considerably the surrounding air. Recognizing, then, the value of the determination of the true conditions of the free air, let us consider what methods are available for this investigation, which must necessarily be sporadic and of shorter duration than if conducted on mountains. In the writer's opinion, free balloons with aeronauts cannot be recommended on account of the large cost in money, and sometimes the loss of life, which attend their frequent use, while without artificial aids to respiration the aeronaut cannot rise much above five miles. Captive balloons, with observers, have been used in England, and more recently, with self-recording instruments, in Germany, but their height is limited to about two thousand feet by the weight of the lifted cable, and a wind which is sufficient to overcome their buoyancy drives them down and occasions violent shocks to the suspended instruments. A kite-balloon on trial in the German army is intended to combine the advantages of a kite and a balloon, but the cost and the moderate height attainable render it inferior to the simple kite

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ON OBTAINING METEOROLOGICAL RECORDS IN THE UPPER AIR BY MEANS OF KITES AND BALLOONS.

By A. Lawrence Rotch.

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The gains were then 17.8 per cent and 17.0 per cent of the weight of substance taken, while the formula $Cu(C_2H_3O_2)_2 4\,NH_3$, requires a gain of 15.8 per cent. Here again the error is due to the great hygroscopic power of the resulting compound, — which absorbed all of the traces of water in the ammonia, — as well as to the fact that the tube had to be weighed while very cold. Since the errors in an analysis of the final compound must necessarily, as before, be in the opposite direction to the errors just cited, the following analysis was made: (6) 1.208 grams of substance required for neutralization 18.75 cubic centimeters of normal acid, thus having contained 26.5 per cent of ammonia. The theoretical amount corresponding to $Cu(NH_3)_2\,(C_2H_3O_2)_2 2NH_3$ is 28.0 per cent. Greater exactness than this would have demanded great elaboration of experimental detail, on account of the excessive instability of the compound.

These analyses and syntheses afford conclusive evidence that the compound diammon cupriammonium acetate exists, and that it, together with the most highly ammoniated cupriammonium bromide, is formed by the action of ammonia upon cupriammonium acetobromide.

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The weights gained were equal to 22.7 per cent and 22.2 per cent of the original weight, while a gain of $3\,NH_3$ would have corresponded to 21.51 per cent. The error of this result is not greater than might have been expected, considering the fact that the deep blue powder was extremely hygroscopic, and that it was necessary to weigh the tube while this was still ice-cold, in order to avoid loss of ammonia. A single analysis, although not exact, served to confirm sufficiently the formula of the resulting substance.

(3) 1.809 grams of the substance required 29.6 cubic centimeters of normal acid to neutralize the ammonia contained in it. This corresponds to 28.2 of ammonia instead of the theoretical 30.3. The loss occurred during the transferrence from the tube to the retort, for the substance is excessively unstable.

The new substance, empirically $CuBrC_2H_3O_2 5NH_3$, dissolved easily in water with the formation of a fine deep blue solution, which lost ammonia upon exposure to the air, and soon deposited a basic salt of copper. Exposed in a dry state to dry air, the substance lost ammonia with great rapidity, and turned distinctly green in color. The only green compound which could be formed under these conditions was $Cu(NH_3)_2Br_2$, and hence the color change was proof that the ammonia had decomposed the original cupriammonium acetobromide according to this reaction: —

$$2\,Cu(NH_3)_2BrC_2H_3O_2 + 6\,NH_3 = Cu(Br)_2 6\,NH_3 + Cu(C_2H_3O_2)_2 . 4\,NH_3.$$

Upon exposure to the air the compound $CuBr_2 6NH_3$, which has recently been discovered in this laboratory,* is known to lose ammonia with conversion into the likewise newly discovered $CuBr_2 . 2\,NH_3$.

The other compound represented above, $Cu(C_2H_3O_2) 4\,NH_3$, has not heretofore been made. Foerster, who tried to prepare it, was unable to make cupric acetate absorb anything like its full complement of ammonia, because he did not cool the mixture.† The only step necessary for the final proof of the reaction given above was then the preparation of diammon cupriammonium acetate, $Cu(NH_3)_2C_2H_3O_2 . 2\,NH_3$, by the action of ammonia gas upon cupriammonium acetate at very low temperatures.

Under conditions precisely like those of Experiments 1 and 2, the two following syntheses were made: —

	(4)	(5)
Weight of $Cu(NH_3)_2(C_2H_3O_2)_2$ taken =	0.4380	1.0324
Weight of substance formed =	0.5160	1.2082
Gain in weight	0.0780	0.1758

* Berichte der deutsch. ch. G., XXIII. 3790. † Ibid., XXV. 3416.

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ON THE ACTION OF AMMONIA UPON CUPRI-AMMONIUM ACETOBROMIDE.

By Theodore William Richards and Robert Jay Forsythe.

Presented May 13, 1895.

It is well known that there is a large class of cupriammonium compounds which contain two molecules of ammonia for each molecule of the cupric salt. The compounds of this class are by far the most stable of the cupriammonium compounds; they are usually permanent in the air, and many of them may be heated above 100° without decomposition. They have, as a general rule, the power of absorbing more ammonia if exposed to an atmosphere of this gas; but the additional ammonia is expelled with the greatest ease. For this reason the compounds containing little ammonia have been assumed in the series of papers of which this is one to be the normal cupriammonium compounds, and any extra ammonia in any other class of compounds has always been designated in the name of this new class. For instance, "tetrammon-cupriammonium bromide" indicates $Cu(NH_3)_2Br \cdot 4\,NH_3$ or $CuBr_2 \cdot 6\,NH_3$.

To the class of stable normal cupriammonium compounds belongs the salt $Cu(NH_3)_2BrC_2H_3O_2$, which was recently discovered by one of us.* The possible absorption of more ammonia by this double salt promised to be a question of much interest; and it is with this question that the present paper is concerned.

A weighed amount of finely powdered pure cupriammonium acetobromide was introduced into a weighed glass tube, so drawn out and bent that the part containing the salt could be immersed in a freezing mixture. Through this tube was passed dry ammonia until the substance, which absorbed a large quantity of gas, remained constant in weight. In two experiments the weights were as follows: —

		(1)	(2)
(2)	Weight of substance taken	= 0.9904	1.4801
	Weight of substance found	= 1.2157	1.8090
	Gain in weight	0.2253	0.3289

* Berichte der deutsch. ch. G., XXV. 1492.

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CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE.

ON THE ACTION OF AMMONIA UPON CUPRI-AMMONIUM ACETOBROMIDE.

By Theodore William Richards and Robert Jay Forsythe.

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sary to attribute it to free spaces within the carbon dioxide molecule. For it is not improbable that the inherent density of massive atoms like those of mercury may be considerably greater than that of light atoms, such as those of carbon and oxygen.

In closing, we desire to point out that the principle here established, that atoms and molecules are of the same order of magnitude, and that no considerable free interatomic spaces exist within the molecule, is in accordance with the remarkable fact that the molecular cross-section of most comparatively simple molecules is approximately an additive property calculable from certain constant values of the atomic cross-section.* This fact would be unintelligible, were the principle not correct; for if considerable space existed between the atoms, it is not to be supposed that those spaces would be the same in entirely dissimilar molecules, — that, for example, the space between the hydrogen and chlorine atoms in hydrochloric acid would have any relation to the space between the atoms in the elementary gases hydrogen and chlorine.

* See O. E. Meyer, Kinetische Theorie der Gase, p. 209.

Rogers Laboratory of Physics,
September, 1896.

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SECOND SERIES.

$$\frac{\eta_{Hg}}{\eta_{CO_2}} = 0.08. \qquad \frac{\eta_{Hg}}{\eta_{H_2}} = 4.04. \qquad \frac{\eta_{CO_2}}{\eta_{H_2}} = 1.94.$$

The relative values for mercury and carbon dioxide agree within about four per cent. That of the second series is, however, more reliable, for the reason above stated, and will be used in the subsequent calculations. It may be stated that the value of the ratio $\eta_{CO_2} : \eta_{H_2}$ at ordinary temperature is 1.72,* somewhat smaller than that found by us at 357°, a result which is in accordance with the greater temperature coefficient of carbon dioxide established by several investigators.

The corresponding values of the relative mean cross-sections as calculated by formula (1) are

$$\frac{q_{Hg}}{q_{CO_2}} = 1.02; \quad \frac{q_{Hg}}{q_{H_2}} = 2.48.$$

That is to say, the average cross-section of the mercury molecule or atom is very nearly the same as that of the carbon dioxide molecule, and is about 2½ times as large as that of the hydrogen molecule. This last result does not differ very greatly from that (2.68) corresponding to the relative molecular volumes of mercury and hydrogen as calculated for 300° by Koch.

These results indicate that *atoms and molecules are of the same order of magnitude*, and that the spaces between the atoms within the molecule, if any exist, are not large in comparison with those occupied by the atoms themselves, and consequently the viscosity of gases, or any other property which like it is dependent only on the size or form of the molecules, is not adapted for distinguishing between monatomic and polyatomic molecules.

In considering the significance of the above values of the cross-section, the different masses of the various molecules, to be sure, ought not to be entirely disregarded. The mercury and carbon dioxide molecules have, as we have seen, the same cross-section, and therefore, assuming both to be of the same general form, they occupy the same volume. The mass of the former is, however, 4.55 times as great as that of the latter. The density of the mercury molecule is consequently greater in this same proportion. But this difference is not marked enough to make it neces-

* O. E. Meyer, Kinetische Theorie der Gase, p. 142.

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SERIES II.

LARGE CAPILLARY.

	p_1	$p_1 - p_2$	t	w	$w : t$	$\frac{w \times 10^{10}}{tm(p_1^2 - p_2^2}$
Hg	769	150	1	1.548		
	769		1	1.548	1.548	374
	769	300	1	2.763		
	769		1	2.764		
	769		1	2.739	2.755	373
CO_2	765	150	1	0.704		
	765		1	0.706	0.705	774
	765	300	1	1.267		
	765		1	1.264	1.265	779
H_2	766	150	1	0.557		
	766		1	0.557	0.557	1517
	766	300	1	1.009		
	766		1	1.006	1.008	1496
Hg	766	300	1	2.728		
	766		1	2.746		
	764		1	2.743	2.739	371

vapor after completion of those with carbon dioxide could not be made as in the former case, in consequence of which it is not certain that a stoppage did not occur in the course of the series. While there was nothing to indicate that such was the case, yet on account of its extremely small bore it was much more liable to stoppage than the larger capillary. We consider the experiments with the latter to be certainly accurate within two per cent.

Nevertheless the agreement between the results of the first and second series is perhaps as close as could be expected with capillaries so different from each other in character. The relative viscosity coefficients of the different gases were calculated from the values of the last column in the table by means of formula (2). The results are as follows.

FIRST SERIES.

$$\frac{\eta_{Hg}}{\eta_{CO_2}} = 2.17.$$

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(See expression (2), page 229.) As the headings indicate, the first of these two series of experiments was made with the smaller, and the second with the larger capillary. It will be seen that in the second series two sets of determinations are given for mercury vapor: the first of these was made before and the second one after the experiments with carbon dioxide and hydrogen, and their agreement shows that the capillary had undergone no change by stoppage or otherwise during the course of the experiments with it.

SERIES I.

SMALL CAPILLARY.

	p_1	$p_1 - p_2$	t	w	$w : t$	$\frac{w \times 10^{10}}{lm(p_1^2 - p_2^2)}$
Hg	753	200	$1\frac{1}{2}$	0.738		
	753		$1\frac{1}{2}$	0.740		
	755		$1\frac{1}{2}$	0.745	0.494	93.6
	755	300	1	0.685		
	755		1	0.686	0.686	93.6
	754	400	1	0.834		
	754		1	0.831	0.833	93.9
CO_2	752	200	1	0.237		
	752		1	0.239		
	752		$1\frac{1}{2}$	0.357	0.238	205
	759	300	1	0.329		
	759		1	0.327		
	766		1	0.324	0.327	203
	766	400	1	0.400		
	766		1	0.396		
	759		1	0.396	0.397	202

Attention may be first called to the agreement of the values of the last column in the case of the transpiration of the same substance under different differences of pressure, thus proving that the effect of pressure is in close accordance with that required by the formula, and consequently that the capillaries are of sufficient length and small enough bore to give the true values of the viscosity coefficients.

Of the two series of experiments the first one made with the smaller *capillary is to be regarded as the less reliable by reason of the fact that,* owing to an accident to the capillary, check experiments with mercury

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could easily be maintained constant to 0.2 or 0.3 mm., or even closer. After a sufficient time, usually sixty minutes, the clamp was closed, and at a noted instant the bulb was removed and subsequently weighed. Check experiments were made in this way at each of two or three different pressures.

The capillary was now removed from the cylinder and the opening B (Fig. 1) carefully closed by fusion. A glass tube long enough to project beyond the upper end of B (Fig. 2) was fused into the end C, and the capillary was then ready for the experiments with carbon dioxide and hydrogen. It was replaced in the cylinder as before, and the glass tube projecting through B connected through suitable wash-bottles with the gas generator. The carbon dioxide was made in a Kipp generator by the action of dilute sulphuric acid on lumps of pure fused sodium carbonate, and was dried by passing through two Allihn gas wash-bottles containing strong sulphuric acid. The hydrogen was prepared from pure Bertha zinc and dilute sulphuric acid, was washed with caustic soda solution and dried by sulphuric acid, as in the case of the carbon dioxide. In order to maintain the gas entering the capillary at atmospheric pressure, a T-tube was inserted between the wash-bottles and the capillary, and its perpendicular arm was turned downwards and caused to dip into sulphuric acid barely below its surface. The cock of the generator was opened sufficiently to cause the gas to bubble out steadily through the sulphuric acid.

The transpiration measurements were made as in the case of mercury. The carbon dioxide flowing through in a definite time was determined by absorption in weighed tubes filled with lumps of soda lime. The hydrogen was burnt by passing it over hot copper oxide contained in hard glass tubes from which the air was previously displaced by carbon dioxide, and the water collected in weighed calcium chloride tubes.

The results are presented in the following table. In the first column is given the symbol of the substance; in the second, the atmospheric pressure p_1; in the third, the difference in pressure $(p_1 - p_2)$; in the fourth, the time t expressed in hours; in the fifth, the weight w in grams of the substance weighed; in the sixth, the mean weight transpired in one hour as computed from the separate check experiments; and in the last, the quotient obtained by dividing this weight by the molecular weight m of the substance, the time, and the pressure function $(p_1^2 - p_2^2)$.*

* In the calculation of this quantity the same mean value of p_1 was used in all the experiments of each series, namely, 760 for those with the smaller capillary, 765 for those with the larger.

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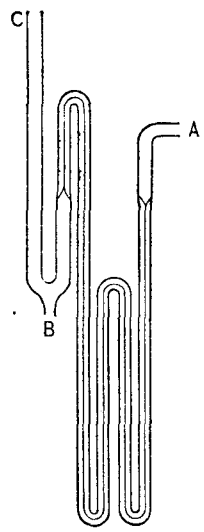

Fig. 1.

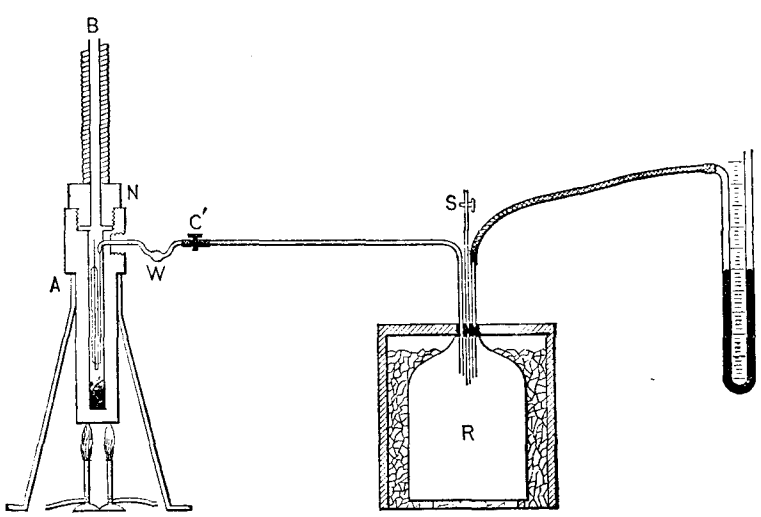

Fig. 2.

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the plate were perforated in the centre, and into the latter was welded an open iron tube *B*, projecting 25 cm. in length and 1½ cm. in diameter. The cylinder was covered, except on the bottom, with a jacket of asbestos about 5 cm. thick, and the projecting tube *B*, which was to serve as a condenser, was wound with spirals of copper wire to increase the cooling surface. Pure mercury was placed in the cylinder and boiled vigorously by means of a number of lamps beneath. The capillary was thus kept at the boiling temperature of mercury under atmospheric pressure. No regard was paid to the variations of temperature arising from changes in barometric pressure, as their effect would evidently be entirely negligible.

Any desired difference of pressure at the two ends of the capillary was attained by inserting a tube in the ground joint and connecting it with a large air reservoir, *R*, which was itself connected through the cock *S* with a suction pump and with an open mercury manometer, *M*. The gas or vapor entered at the other end of the capillary always under atmospheric pressure. The whole apparatus in the form used for measuring the rate of transpiration of the mercury vapor is shown in Figure 2.

In making the experiments, the rate of flow of the mercury vapor was first determined in the following manner. While the cylinder was being heated, carbon dioxide was forced through the capillary to prevent the condensation in it of liquid mercury and the formation of its oxide. After the mercury was boiling actively, and its vapor entirely enveloped the capillary, as shown by a mercurial thermometer inserted into the tube *B* (Fig. 2), it was connected with the suction pump, and mercury vapor drawn through for half an hour. The carefully ground end of a weighed bulb, *W*, was then inserted in the ground joint, its other end being connected by means of a clamped rubber tube, *C*, with the air reservoir, in which the desired reduction of pressure had been produced. At a definite moment the clamp *C* was opened and the time noted. As the volume of the condensing bulb *W* was very small compared with the volume of the air reservoir, no sensible change in the pressure was thus produced. The mercury vapor was found to be completely condensed in *W* about two to three centimeters from the ground joint. It was found that a slight and unavoidable leakage * through the ground joint occurred, and it was therefore necessary to readjust the pressure occasionally. It

* In the case of the mercury experiments no error could arise from this source, as the leakage was inward. In the case of those of carbon dioxide and hydrogen, it was proved by blank experiments that the amounts of carbon dioxide and water which leaked in were less than one per cent of the total weight.

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in measuring the quantities of the different gases which under a constant difference of pressure passed in a given time through the same capillary kept at a definite constant temperature. O. E. Meyer* has derived the following formula for calculating the viscosity coefficient of a gas from its rate of flow through a capillary tube:

$$\eta = \frac{\pi}{16} \frac{R^4}{\lambda} \frac{(p_1^2 - p_2^2)\, t}{p_1 V_1},$$

where λ is the length and R the radius of the tube, t the time, p_1 the pressure at which the gas enters and p_2 at which it leaves the tube, and V_1 the volume of the transpired gas measured at the pressure p_1. In case of comparative experiments made with the same capillary on two different gases, the following proportion holds true:

$$\eta_1 : \eta_2 :: \frac{(p_1^2 - p_2^2)_1\, t_1}{n_1} : \frac{(p_2^2 - p_2^2)_2\, t_2}{n_2}, \qquad (2)$$

in which n_1, n_2, represent respectively the number of gram molecular weights of the two gases transpired, — since n is proportional to the product pV.

The apparatus and experimental method that we employed were necessarily quite different from the usual ones, and they will therefore be briefly described. The capillary used in the most complete series of experiments consisted of a glass tube about 74 cm. in length and 0.34 mm. in internal diameter (determined by measuring the volume of a known length by means of mercury). A smaller capillary about 49 cm. in length and 0.22 mm. in diameter was used in a preliminary series. The capillary was bent in the manner shown in Figure 1, except that, as actually constructed, it was made much more compact. To its ends were fused pieces of ordinary glass tube, as shown in the figure; one of these was provided at the point A with a ground glass joint. The capillary was placed in a vertical position in a heavy steel cylinder (see A, Fig. 2) 30 cm. high, 2.8 cm. internal diameter, having a small orifice at the side, through which the ground joint protruded for a distance of about one centimeter. The capillary was held in position in the orifice by packing with loose asbestos. Although the capillary was vertical, the influence of gravity was eliminated by reason of the fact that the ascending and descending parts were made equal in length. The top of the cylinder was closed by an iron plate screwed down with a nut, N; the nut and

* Pogg. Ann., CXXVII. 269.

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$$L = \frac{1}{4\sqrt{2}\,Nq},$$

whence it follows that

$$\eta = \frac{1}{4\pi\sqrt{2}}\,\frac{mc}{q};$$

or for any two different gases,

$$\eta_1 : \eta_2 = \frac{m_1 c_1}{q_1} : \frac{m_2 c_2}{q_2}.$$

But, since for any two gases at constant temperature,

$$m_1 c_1^{\,2} = m_2 c_2^{\,2},$$

the above proportion may be simplified to the following equation:

$$\frac{q_1}{q_2} = \frac{\eta_2}{\eta_1}\,\sqrt{\frac{m_1}{m_2}}; \qquad (1)$$

from which it is evident that the relative mean cross-sections of the molecules of the two gases are readily calculated from their molecular weights and viscosity coefficients. It was thought by us that monatomic molecules might prove to be much smaller than polyatomic ones, since it seems *a priori* not improbable that the spaces between the atoms of the latter are large in comparison with the dimensions of the atoms themselves. The experiments to be here described show, however, that no marked distinction exists between monatomic and polyatomic gases in this respect.

Experiments on the viscosity of mercury vapor, and especially on the effect of temperature upon it, have been already made by S. Koch,* who calculated that at 300° the volume of mercury molecule is 4.4 as great as that of the hydrogen molecule. As this calculation was not based on direct comparative experiments made by passing the two gases through the same capillary, but was an indirect one involving the measurements of different experimenters, and the dimensions of the capillaries used by them, it seemed desirable to subject the matter to further investigation in the direct manner indicated. Moreover, the author does not discuss the significance of his result in its bearing on the relative magnitude of atoms and molecules.

The method used by us in determining the relative viscosity consisted

* Wied. Ann. Phys. Chem., XIX. 857, 1883.

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THE VISCOSITY OF MERCURY VAPOR.

By A. A. Noyes and H. M. Goodwin.

Presented October 14, 1896, by Charles R. Cross.

The uncertainty which attaches to the specific heat ratio of gases as a means of distinguishing between monatomic and polyatomic molecules has been recently made evident by the extended discussions of the significance of that property in connection with the atomic weights of argon and helium. It is therefore of great interest to investigate other properties which may be expected to be related to the atomicity of the molecule. Of such properties those dependent on the volume or cross-section of the molecules seem most promising. We have therefore undertaken the investigation of one of these, the viscosity or internal friction, in order to determine whether a marked difference in its value exists in the case of gases with monatomic and those with polyatomic molecules. To this end we have made comparative measurements of the viscosity of hydrogen, carbon dioxide, and mercury vapor at the boiling temperature of the last named substance.

According to the Kinetic Theory of Gases the viscosity coefficient has the theoretical significance expressed by the following equation,*

$$\eta = \frac{1}{\pi} NmLc,$$

in which N is the number of molecules in the unit of volume, m the mass of a single molecule, L the mean free path, and c the mean velocity. Moreover, the free path L is dependent solely on the number of molecules N and the mean cross-section q of a single molecule, or its sphere of action.†

* O. E. Meyer, Kinetische Theorie der Gase, 1st ed., pp. 130, 139.

† Ibid., pp. 206, 218. The symbol Q used by the author represents the total cross-section of all molecules in the unit of volume, and is therefore evidently equal to Nq.

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CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XLVIII. — *THE VISCOSITY OF MERCURY VAPOR.*

By A. A. Noyes and H. M. Goodwin.

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